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Algorithms to Enhance Radar Image

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The Transportation Development Centre
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by

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Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract

The chief objective of this project was to choose the necessary algorithms for the marine radar image enhancement and segmentation. To this end, various image enhancement and segmentation techniques have been implemented and tested. Enhancement methods included linear and non-linear spatial filtering, frequency domain filtering, histogram treatment, thresholding, and mathematical morphology. The segmentation process was subdivided into two categories, namely, edge based and region based techniques. Edge based segmentation methods include convolution with local operators, relaxation labeling on edges and curves, and contour tracing. Region based segmentation techniques include clustering, relaxation labeling on clusters, quadtree, and region splitting and region merging.

This study showed the suitability of using image processing techniques for the enhancement and segmentation of marine radar images. The methods that have shown the best results are based on region based segmentation. These methods have shown good enhancement results for visual correlation between the marine radar and SAR images. Moreover, a set of algorithms was able to find and define ice floes in the marine radar image. This leads to the conclusion that for the end of automatic tracking, the treatment on the marine radar image is ready. The edge based segmentation methods, on the other hand, were more sensitive to the marine radar image noise, but they were found to be effective in visually enhancing the ice floe features when applied after edge detection and overlaying.

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16. Résumé

L'objectif principal de ce projet est d'étudier et de choisir les algorithmes nécessaires pour mettre en valeur les floes de glace et les segmenter à partir d'images radars. Plusieurs méthodes de mise en valeur et de segmentation ont été développées. Les méthodes de mise en valeur sont composées de filtres spatiaux linéaires et non linéaires, filtres dans le domaine de la fréquence, traitement d'histogrammes, segmentation basée sur différents seuils d'intensité et morphologie mathématique. Les méthodes de segmentation sont décomposées en deux catégories: basée sur les bords et basée sur les régions de l'image. La segmentation basée sur les bords présente dans l'image radar consiste à utiliser des méthodes telles que la convolution avec des opérateurs locaux pour déterminer les bords, la relaxation sur les bords pour accentuer l'apparence des bords ainsi qu'un algorithme de recherche des contours. La segmentation basée sur les régions utilise des méthodes de groupement d'objets, de relaxation sur les différents groupes, de division d'image et de fusion des régions.

Ce projet a démontré que les techniques de traitement des images, pour la mise en valeur et la segmentation des images radars, sont convenables et ont produit des résultats concrets. La segmentation des régions a généré de meilleurs résultats que la segmentation basée sur les bords de l'image. Les résultats de la segmentation des régions peuvent être bénéfiques à la fois pour la corrélation visuelle ainsi que pour la définition et la détermination des floes de glaces. Pour la fin de la corrélation automatique, le traitement des images radars est prêt. La segmentation basée sur les bords est plus sensible au bruit, cependant son application après la segmentation sur les régions a montré des résultats satisfaisants visuellement.

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Summary

The chief objective of this project was to implement, test, and choose image processing techniques in order to enhance and segment the ice features present in marine radar images. The goal for the enhancement is to facilitate the visual correlation between the marine radar image and its corresponding SAR image. The segmentation, on the other hand, is used in order to find and define the regions or ice floes in the marine radar image. Once these ice floes are determined, they are valid entities in the computer and therefore can be used for visual enhancement or even for later automatic correlation between the marine radar and the SAR images.

1- Preprocessing of the Marine Radar Image

Many preprocessing methods have been developed for visual enhancement, preparation for edge based segmentation and preparation for region based segmentation. The conclusion was that edge preserving smoothing along with median filtering yielded to the most acceptable results for visual enhancement (this includes enhancement for edges) as well as preprocessing for edge based segmentation techniques. On the other hand, mathematical morphology and median filtering yielded the best results of preprocessing for region based segmentation techniques.

2- Edge Based Segmentation

The goal of segmentation in general is to find regions in an image. Edge based segmentation bases the decision making on edges instead of clusters of dots. At the end of the segmentation of the marine radar image, a set of ice floes is found and defined for later correlation.

No one algorithm showed acceptable results for edge based segmentation because most of the developed techniques were very noise sensitive. This is generally so for edge based segmentation because edge finding involves differentiation, which in its turn increases the amount of noise in an image. It was found, however, that an average filtering with local thresholding followed by a convolution or edge detection has generated good results.

3- Region Based Segmentation

There are two goals behind the application of region based segmentation to the marine radar image, namely, visual enhancement as well as region finding and determination. The goal for region finding and determination is for automatic tracking since the regions would then be valid entities of which moments and other descriptions can be computed. A method based on skeleton finding followed by region splitting and region merging showed good results for defining and determining the regions or ice floes of the marine radar image. These techniques are applied after the preprocessing needed for region based segmentation. After the application of this set of algorithms, the important or most striking ice floes of the marine radar image become valid entities. In the case of segmentation for automatic tracking, the marine radar treatment is completed at this stage and a similar treatment should be applied to the SAR image. The same set of algorithms can not be applied to the SAR image since these images are very different in nature. In the case of visual enhancement based on region determination,

a contour tracing algorithm was implemented in order to define the valid edges of the found regions. These edges can then be overlaid on top of the SAR image.

Results and Recommendations

At this stage, several algorithms of image processing produced promising results. Techniques were found to visually enhance the marine radar image as well as segment it for ice floe finding and validation. The region based segmentation algorithms, as a whole, produced the best results in segmenting the marine radar images.

The techniques developed in this study are now ready to be tested in the real environment. This involves software and probably hardware development for speed considerations. The problem at this stage is that the marine radar component aboard the ship does not lend itself to any considerable development. Therefore, we believe that the marine radar image should be made available on a platform that would permit more development, testing, and implementation of the chosen image processing techniques.

Sommaire

L'objectif principal de ce projet est l'implantation, le test et le choix de techniques de traitement d'image afin de mettre en évidence et de segmenter les caractéristiques des glaciers figurant dans les images de radar marin. La mise en évidence permet de faciliter la corrélation d'une image obtenue à partir du radar marin et celle obtenue par le SAR. Cependant, la segmentation permet de trouver et de définir, sur les images du radar marin, des régions de floes de glaces. Une fois ces régions déterminées, elles représentent des entités qui peuvent à la fois être utilisées pour la mise en évidence visuelle et pour une corrélation automatique avec le SAR.

1- L'avant traitement des images de radar marin

Dans le cadre de cette étude, plusieurs méthodes d'avant traitement d'image ont été développées pour la mise en évidence visuelle en vue d'une segmentation basée sur les bords ainsi qu'une segmentation basée sur les régions. La méthode de conservation des bords par l'égalisation et celle du filtrage médian produirent les meilleurs résultats aussi bien pour la mise en évidence visuelle que pour la segmentation basée sur les bords. Quant à la segmentation basée sur les régions, c'est la morphologie mathématique et le filtrage médian qui ont produit les meilleurs résultats.

2- Segmentation basée sur les bords

En général, le but d'une segmentation est de déterminer des régions spécifiques d'une image. Les résultats d'une segmentation basée sur les bords sont déterminés à partir des bords et non pas sur des agglomérats de points. Suite à la segmentation d'une image de radar marin, des floes de glaces sont localisés et définis et peuvent être utilisés, plus tard, pour une corrélation. La plupart des techniques de segmentation basées sur les bords, développées jusqu'à présent, n'ont pas donné des résultats satisfaisants à cause de leur sensibilité au bruit. Ceci est en général le cas pour la segmentation basée sur les bords, car déterminer les bords implique la différentiation qui augmente l'intensité du bruit dans l'image. Par contre, il s'est avéré qu'un filtrage "médian" avec seuil local suivi d'une convolution ou d'une détection de bords donnent de meilleurs résultats.

3- La segmentation basée sur les régions

Les deux buts principaux de la segmentation basée sur des régions d'une image de radar marin sont: la mise en évidence visuelle, la définition et la détermination des bords. Le but des deux dernières opérations est le retraçage automatique puisque les régions représentent des entités à partir desquelles les moments et d'autres descriptions peuvent être calculés. Une méthode basée sur le squelette suivie d'une subdivision et d'une fusion de régions a donné de bons résultats en ce qui concerne la définition et la détermination de floes de glaces dans l'image obtenue par radar marin. Après l'application de ces algorithmes, les floes de

glaces les plus importants et les plus remarqués deviennent des entités valables. Dans le cas de la segmentation pour un retraçage automatique, le traitement de l'image radar est à présent terminé et un traitement similaire est appliqué à l'image SAR. Cependant, les mêmes algorithmes ne peuvemt être utilisés dans le cas d'une image SAR étant donné que celles-ci sont trés différentes de nature. Dans le cas de la mise en évidence visuelle basée sur la détermination de région, un algorithme de retraçage de contour est implanté afin de déterminer les bords des régions trouvées. Ceux–ci peuvent alors être superposés à l'image SAR.

Résultats et recommandations

Jusqu'à présent, plusieurs algorithmes de traitement d'image ont produit des bons résultats. Des techniques de mise en valeur et de segmentation d'image radar pour la définition et la validation de floes de glace ont été établies. En matière de segmentation, les meilleurs résultats furent obtenus par les algorithmes de segmentation basée sur les régions. Les techniques développées à travers cette étude sont à présent prêtes à être testées dans un environnement réel. Ceci comprend le développement de logiciel et d'équipement afin d'améliorer la vitesse de traitement. Le problème qui se pose est que la composante du radar marin à bord du navire ne permet pas de développements ultérieurs. Nous pensons donc que le système de radar marin devrait être modifié pour permettre de plus amples développements et tests de ces techniques de traitement d'images.

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1. Introduction

Despite the advancements in the Shipboard Ice Navigation Support System (SINSS), a number of deficiencies have been identified by the Transportation Development Centre (TDC) and Canarctic Shipping Ltd. These deficiencies occur in two major categories: the first concerns the difficulties associated with the interpretation of the marine radar image, and the second concerns the manning and training of the navigation officers. It is the purpose of this project to address the first category of deficiencies.

The most difficult aspect of tactical navigation using SAR is the correlation of recognizable features between the marine radar image and the SAR image itself. One recommendation from the 1987 Phase V of SINSS is to investigate various methods of improving the quality of the MARINE-VUE display through signal processing. The techniques examined for the enhancement of the marine radar images included three major categories: Preprocessing, edge based segmentation, and region based segmentation techniques.

The actual problem suggested by Canarctic Shipping and TDC is presented as follows: there are two images available on board, the first is the marine radar image (figure 1) and the second is the SAR image (figure 2) of a certain area; the task is to recognize features in both images in order to position the ship on the SAR image.

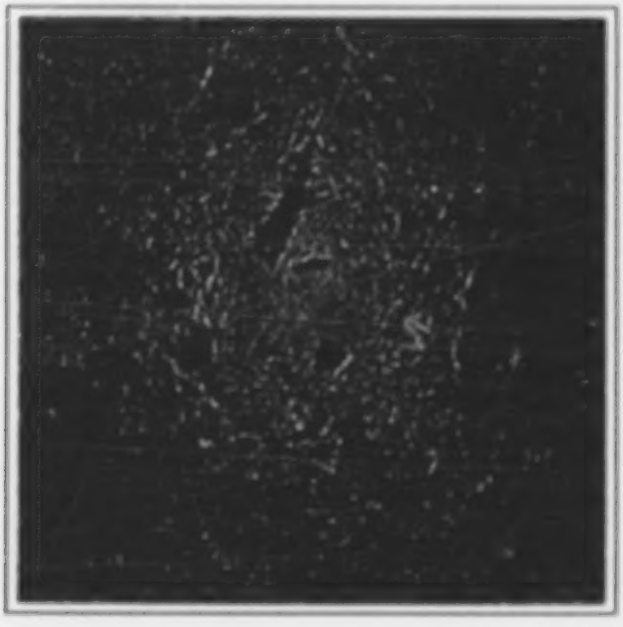

Figure 1 A Marine Radar Image

The features' recognition is performed by an experienced operator. The marine radar image, however, is so unclear that the probability of the operator making a judgement error is

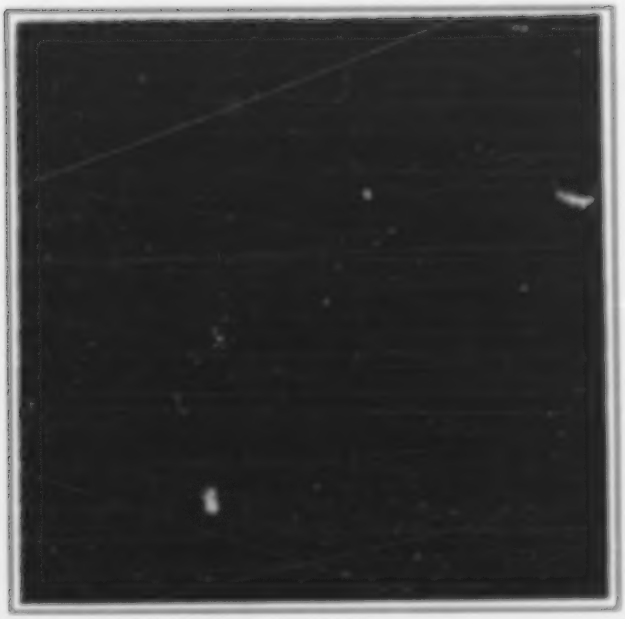

Figure 2 A SAR Image

relatively high. This misjudgment can result in many problems such as a deviation from the desired navigation path, or the ship being trapped in major ice floe region.

The chief objective of this project is to implement various image enhancement and segmentation techniques to aid in the year round navigation of Canadian Arctic waters. This consisted of studying and testing several image enhancement and segmentation algorithms and assessing their effectiveness in determining and highlighting features (ice floes) in the marine radar images. In this report, we present and discuss the algorithms that were developed and tested during this phase of the project.

2. Selected Preprocessing Techniques

This section describes the work accomplished during the study and selection of the preprocessing techniques for the marine radar images. As has been discussed during the first phase of the project, the raw marine radar images are not very suitable for edge based algorithms for segmentation (can still be used for enhancement). This is due to the fact that the images are constructed of clusters of dots rather than defined boundaries. In order to enhance the boundary definition of the clusters, the edge preserving smoothing algorithm, has been retained for implementation aboard the ship.

The marine radar image needs to be preprocessed for region finding and determination also. Both morphology with median filtering have been retained for this task. In order to compensate for STC curve effect in the marine radar image, a range normalization procedure has also been implemented.

2.1 Edge Preserving Smoothing

The simplest smoothing operator used in image processing is generally the average filer. This is simply a convolution mask that contains equal value elements. Thus, the average filter operates by setting each pixel in the image to the average value of the neighboring region. This has the effect of smoothing out small and spurious features. However, it has the undesirable effect of blurring sharp edge features and boundaries in the image. Since every pixel is set to the average value of its immediate neighborhood, the pixels that lie near discontinuities in intensity (edges) are smoothed out.

The edge preserving filter attempts to take this into account when it calculates the new "smoothed" value of the pixel. Instead of only looking at one neighboring region, this algorithm considers the 8 regions around the pixel. The edge preserving then uses a simple heuristic to determine the most appropriate average value for the pixel: the region of the minimum variance is chosen and the pixel value is set to the average value of that region. An area that has an almost constant intensity will have a small variance, while regions with sharp changes in intensity (edges) will have a high variance. Thus, by always smoothing over the neighborhood region of minimum variance, edge features in the image are retained.

The next set of images show the original marine radar image and the result of the edge preserving algorithm.

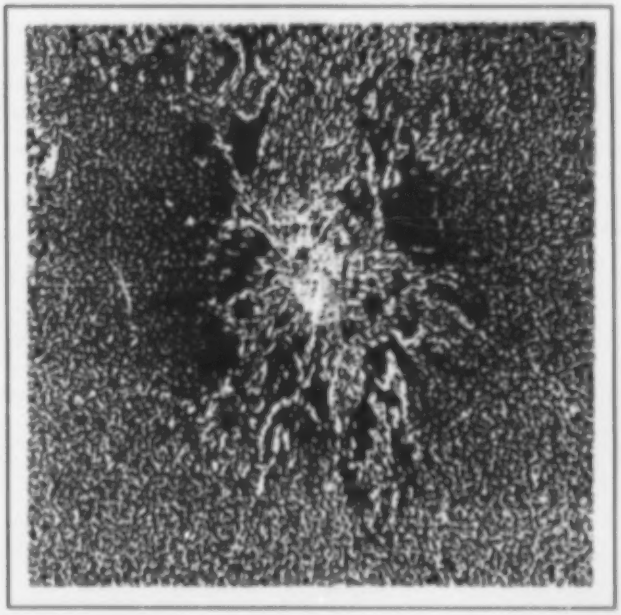

Figure 3 Original image.

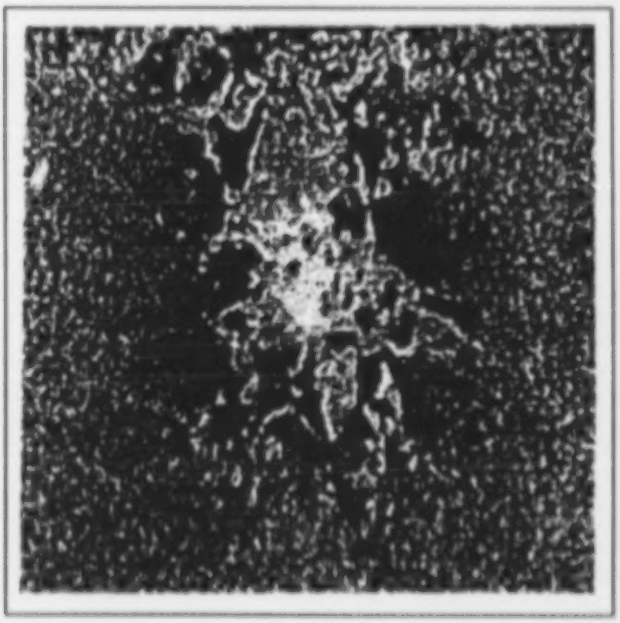

Figure 4 Edge preserving smoothed image.

Figure 5 Original image.

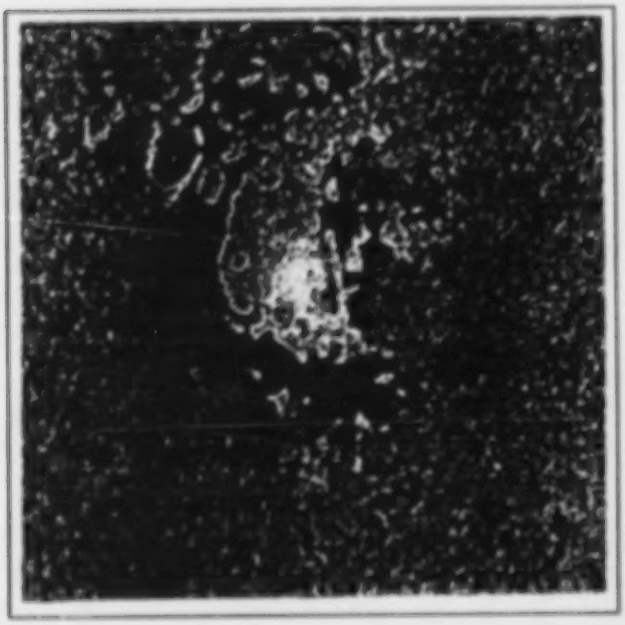

Figure 6 Edge preserving smoothed image.

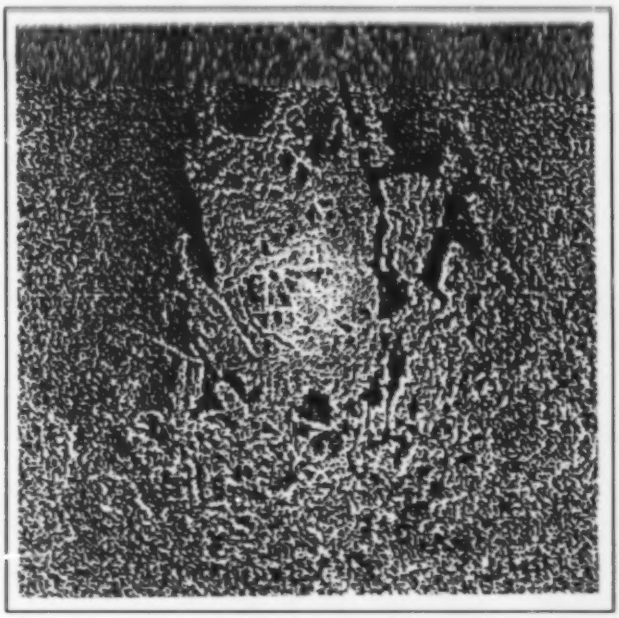

Figure 7 Original image.

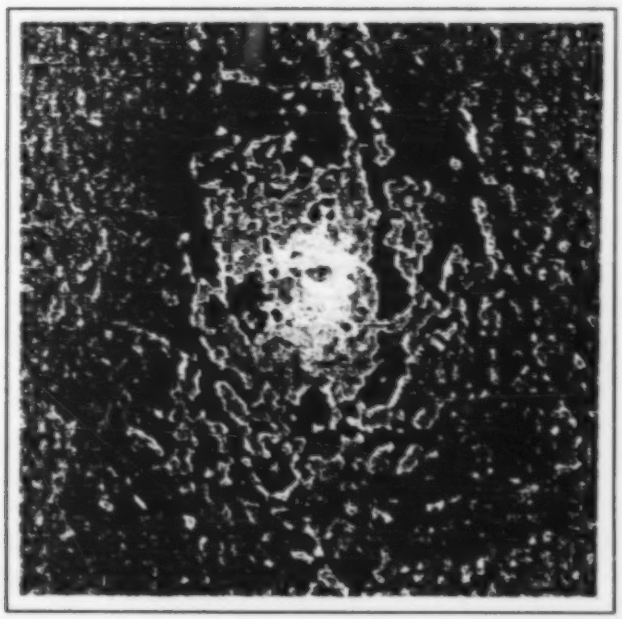

Figure 8 Edge preserving smoothed image.

The following images show the result of applying an edge detector on the previous images and overlaying the result on the original image.

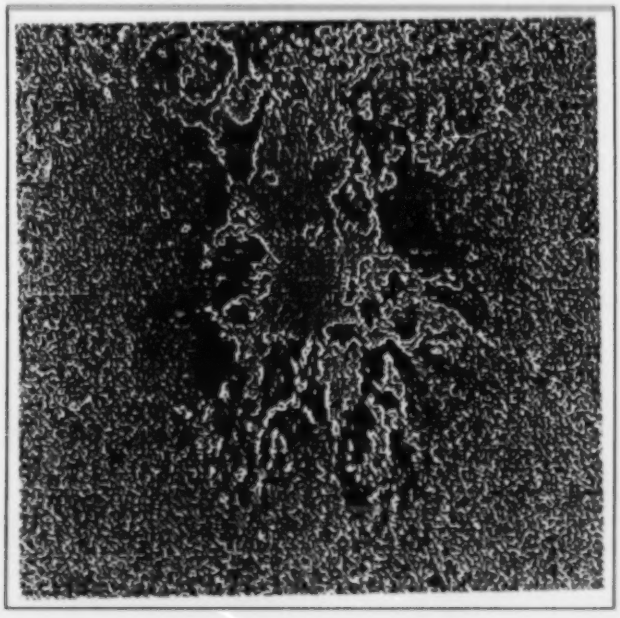

Figure 9 Result from Figure 3.

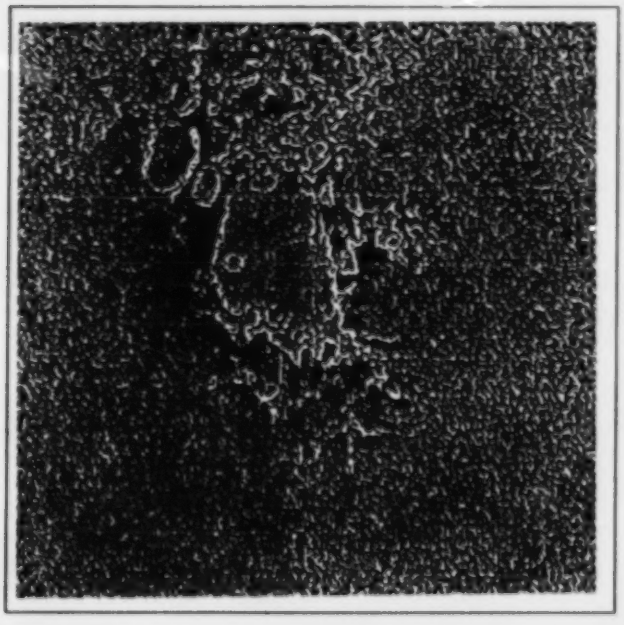

Figure 10 Result from Figure 5.

Figure 11 Result from Figure 7.

2.2 Preprocessing for Region Based Segmentation Techniques

Two preprocessing methods have been retained in order to make the marine radar image more suitable for region based techniques: Median Filtering and Mathematical Morphology.

2.2.1 Mathematical Morphology

Mathematical morphology essentially involves repeatedly expanding and contracting and image locally. This has the effect of removing small features by grouping together and unifying similar regions. In general, the expansion is applied before the contraction on the image. In the case of a grey level image, This involves setting all the neighborhood of a certain pixel to the maximum intensity within a window. The contraction sets the neighborhood to the minimum value. This algorithm is conducted in parallel and is very suitable for hardware implementation.

The biggest disadvantage of this algorithm is the difficulty of defining an automatic manner in order to adaptively determine the sequence to be followed on a given image. After many trials on the marine radar images, it was noticed that this algorithm should not be applied more than once in order not to loose the small features of ice floes. The following images show the result of one expansion and one contraction followed by a low pass filter in order to smooth the outcome of morphology.

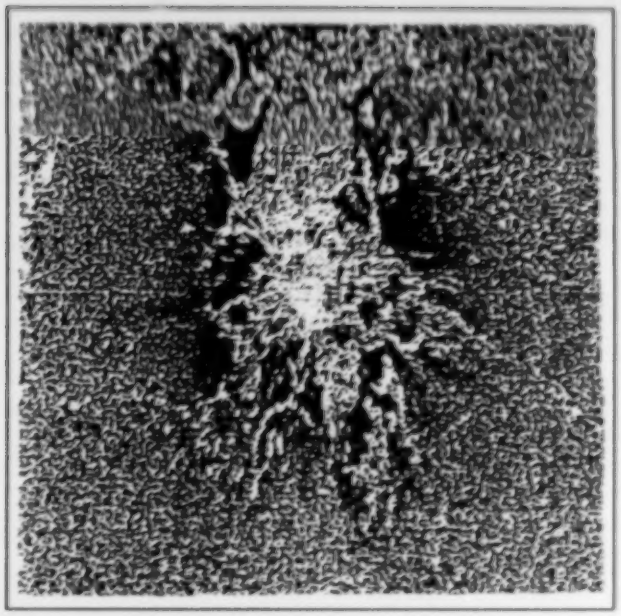

Figure 12 Original image.

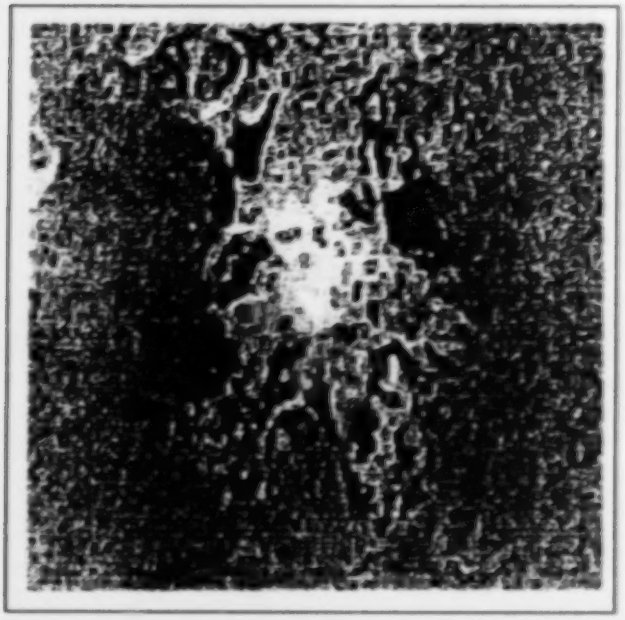

Figure 13 Effect of Morphology on the Previous Image.

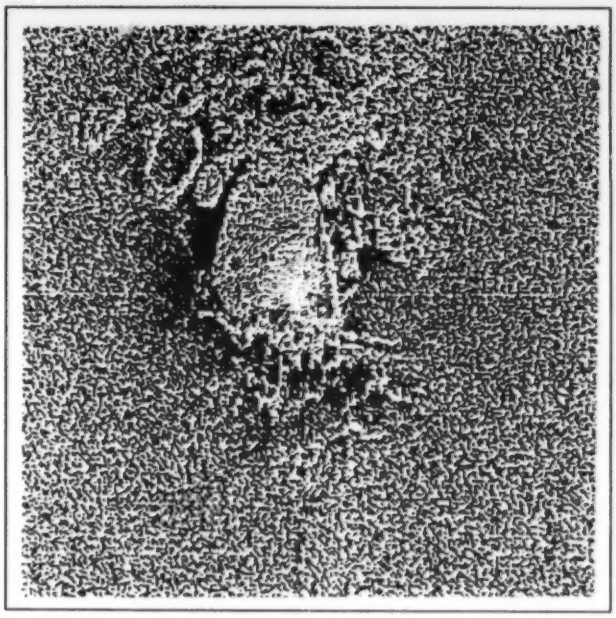

Figure 14 Original image.

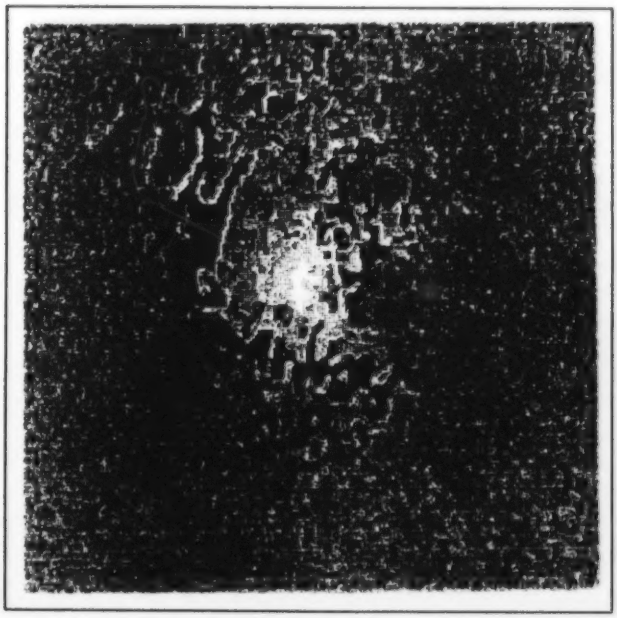

Figure 15 Effect of Morphology on the Previous Image.

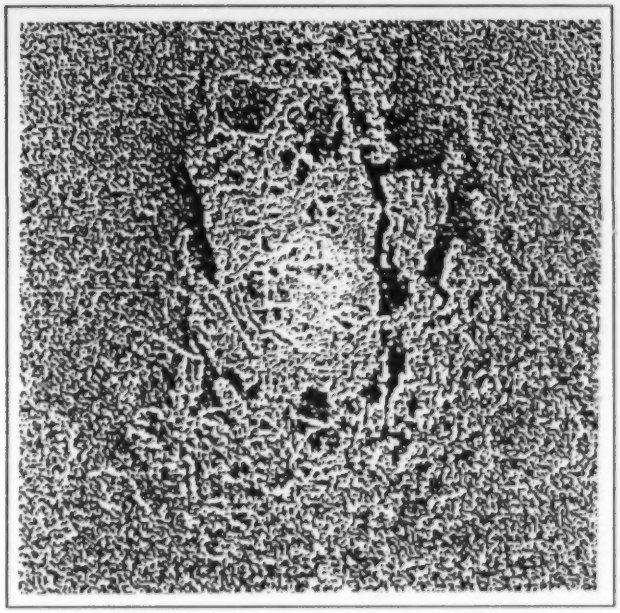

Figure 16 Original image.

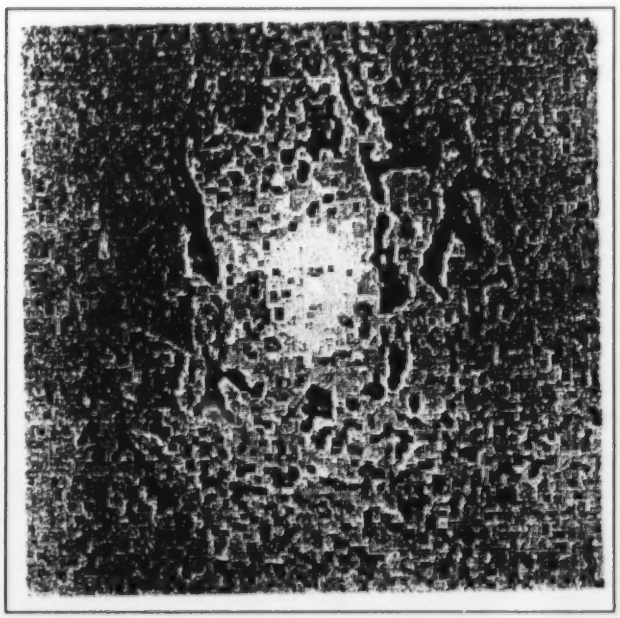

Figure 17 Effect of Morphology on the Previous Image.

2.2.2 Median Filtering

With the median filter, the p elements inside a local operator window are stored by value. The resultant output image element is the $(p+1)/2$ highest value of the series. However, with this process, the bright edges do not lose very much sharpness as in the case of the average filter. After many trials, we found that the window size should not exceed 5×5 in order to keep enough detail about the boundary of ice floes. The results are show next.

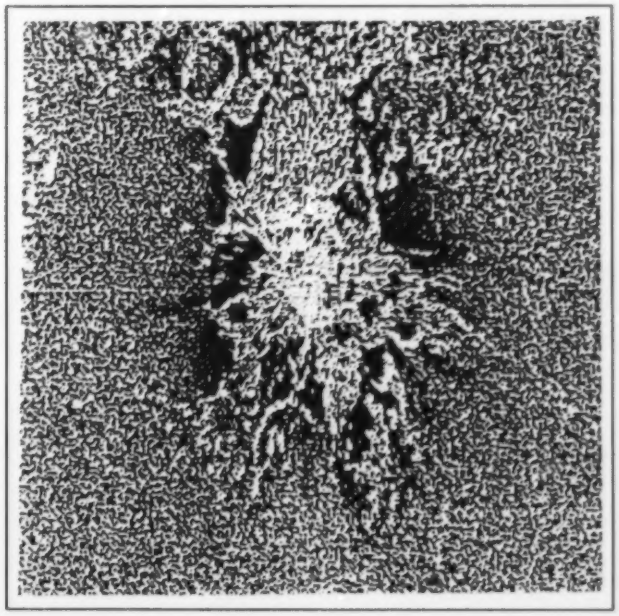

Figure 18 Original image.

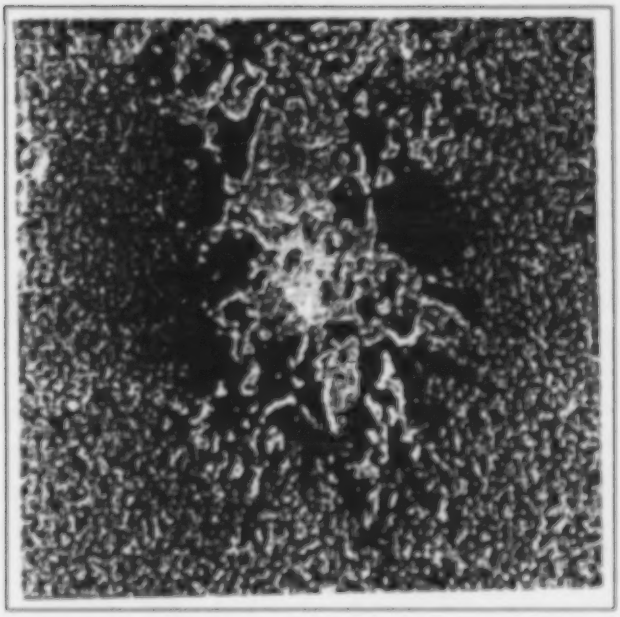

Figure 19 Effect of a 3x3 Median on the Previous Image.

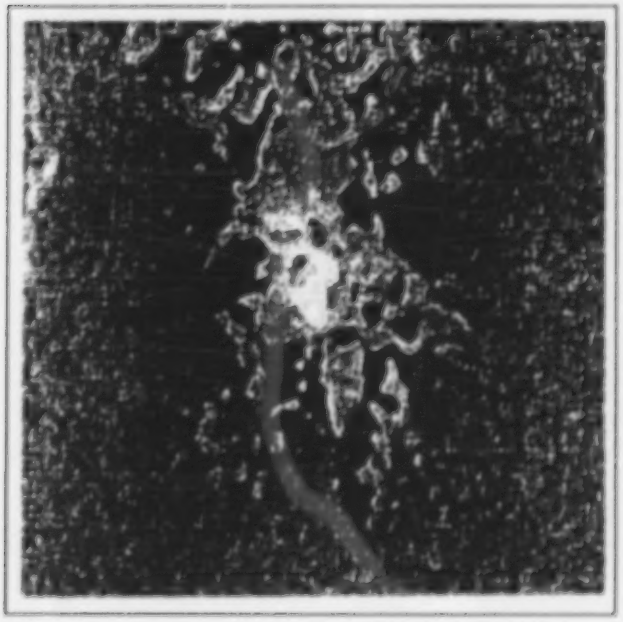

Figure 20 Effect of a 5x5 Median.

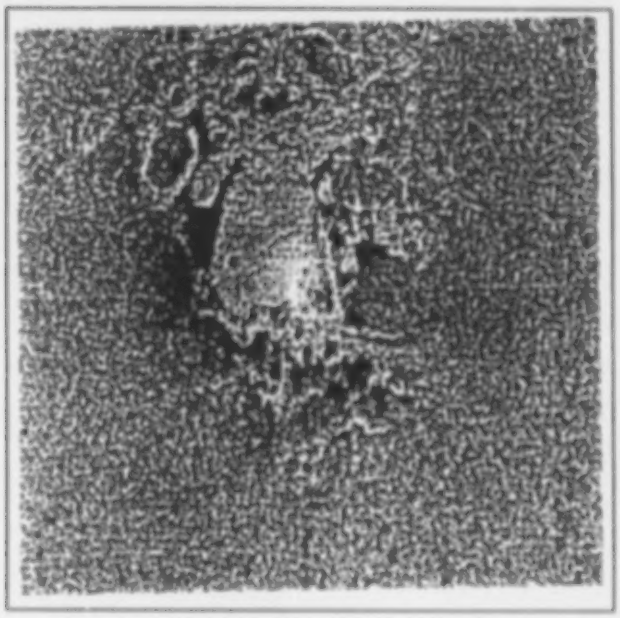

Figure 21 Original image.

Figure 22 Effect of a 3x3 Median on the Previous Image.

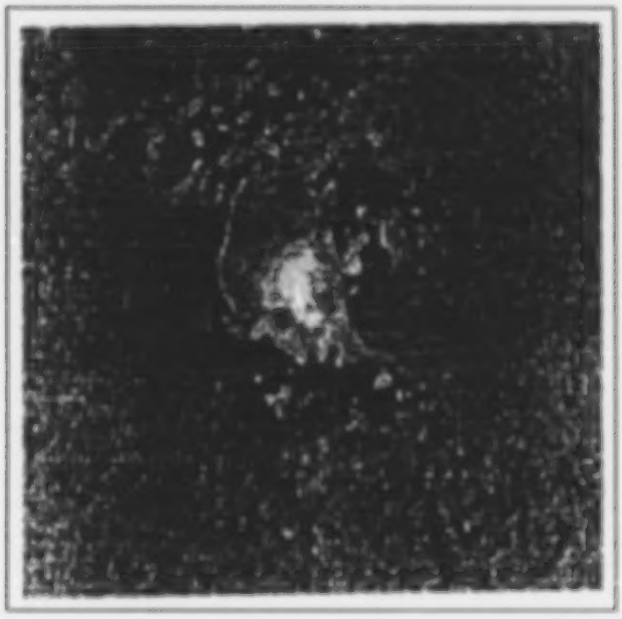

Figure 23 Effect of a 5x5 Median.

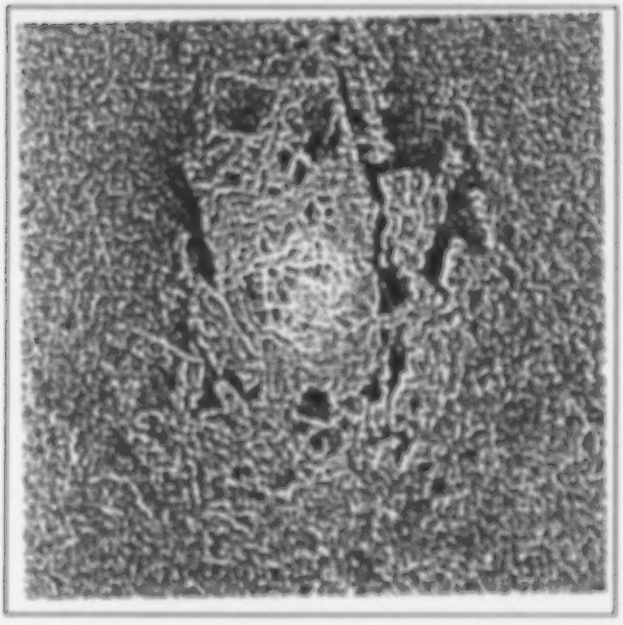

Figure 24 Original image.

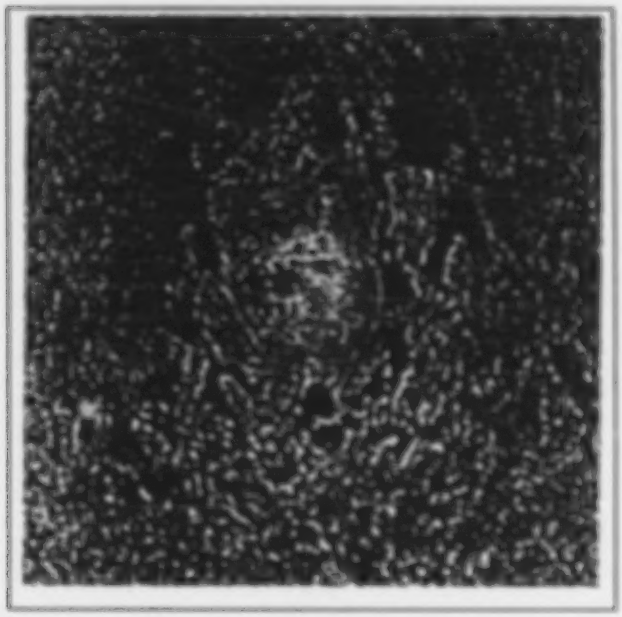

Figure 25 Effect of a 3x3 Median on the Previous Image.

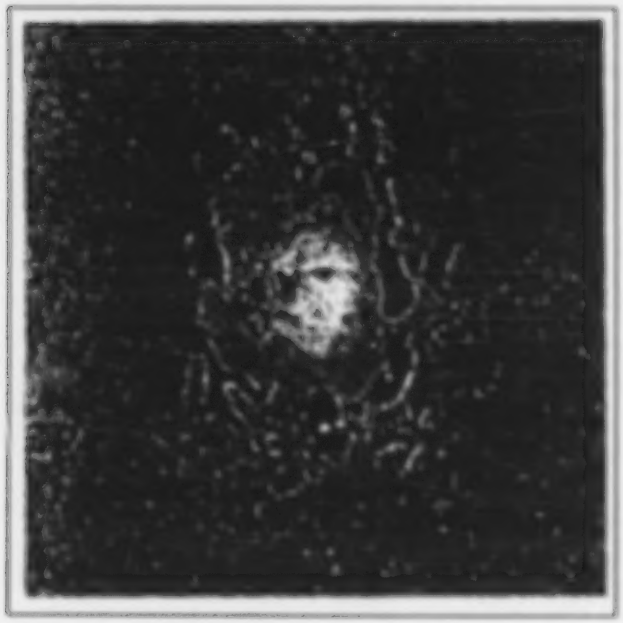

Figure 26 Effect of a 5x5 Median.

The three methods, namely, edge preserving smoothing, median filtering, and mathematical morphology have been tested and retained as preprocessing algorithms for either edge based or region based processing. Edge preserving smoothing is a low pass filter that had been retained

in order to smooth the marine radar image while keeping as much information as possible about the edges. The median filter has also been retained in order to smooth the image for processing using region based techniques. Mathematical morphology has been retained in order to connect and distribute the intensity more uniformly along the edges defining the ice floes, this can also be used as a preprocessing method for region based segmentation techniques.

3. Selected Edge based Segmentation Techniques

This section describes the work accomplished in the coding and final testing of the edge-based enhancement and segmentation techniques. This will include a description of the retained algorithms, the results obtained from their preliminary application and the conclusions obtained thereof.

As previously mentioned in TP#8932E, the marine radar images do not lend themselves well to edge based enhancement techniques. These methods cannot be directly applied chiefly because of two reasons. First, the marine radar image is very noisy and since most edge-based image enhancement algorithms are differential in nature, the noise, which is mainly caused by sea-clutter, becomes amplified. Second, due to the means by which the ice floes are defined on the marine radar images, there are no well defined edges and boundaries. The boundaries in the marine radar image are caused by protruding pieces of ice that have been pushed up along the borders of the ice floes, which reflect the radar wave.

After many trials, it was notices that the Radar-SAR operator uses two kinds of information in order to correlate both types of images: ice floes (imposing in size, unusual features, very hard ice content ...) and edges (caused by imposing ridges, unusual shaped ridges ...). This has put the emphasis on the fact that both region based segmentation as well as edge based segmentation are needed. The ice floes can be found using some region based technique, however, the ice ridges can only be found using edge based techniques.

We should point out at the beginning of this section the fact that the marine radar images used for testing seemed to be too noisy. The reason for this additional noise is not known yet. Trials for correcting the initial marine radar images based on STC curve and thresholding schemes, as suggested by Canarctic Shipping Limited, were not successful. Therefore, the available images were used for the rest of the project.

Many different edge-based image enhancement and segmentation algorithms have been studied, developed, and evaluated. The major methods as well the results they produced are discussed below.

3.1 Convolution Masks

The simplest edge detectors are based on convolution masks. Many different operators exist and each, being based on different principles, have different effects on radar images. To begin, the simplest edge-detecting operator is the Prewitt operator. The operator is a discrete approximation of the first directional derivative, or gradient, of a two dimensional

function. There is a multitude of first order derivative operators for edge detection in general. As explained in TP#8932E, many of them have been implemented but did not show good results when applied to marine radar images. This was to be expected due to the nature of the images and its noise content. The next logical progression in edge operators is the second degree differential operators. These operators are generally even noisier due the higher degree of differentiation. At this stage, we are rather sure that differential operators should not be applied on the raw marine radar image due to the tremendous noise amplification. If the image is properly preprocessed, then these operators may yield "acceptable" results, as will be shown later in this report.

3.2 Transform Methods

Another broad class of edge-based image enhancement techniques developed is based on transform methods. The purpose behind analyzing the transform of an image is that in the transform domain certain features become more explicit. The Fourier transform is one of the most commonly used and most studied transform technique in signal processing. One of the major reasons behind the popularity of the Fourier transform is that it can be very efficiently implemented via the FFT algorithm. Edges in an image correspond to sharp changes in intensity within a small area in space. The equivalent of this in the frequency (or Fourier) domain, is the presence of energy in the high frequencies. The low frequencies in the transformed image correspond to slowly varying features in the image. Thus to enhance the edges in the image, one often high-passes the Fourier transform, that is to say, suppress the low frequencies and allow the higher frequencies to pass. After many trials, it became apparent that frequency-based methods do not adapt well to the type of images at hand. These methods are rather global in nature and are hard to tune in order to take into account local effects. In addition, highpassing an image tends to accentuate noisy features, which is undesirable for the marine radar image. This can be improved somewhat by band-passing the image (i.e. by also cutting off the very high frequencies). This too, however, is not a good solution, as an analysis of the Fourier Transform of the marine radar images shows that most of the energy is concentrated in the very low and the very high frequencies.

3.3 Relaxation Labeling

Another edge-based enhancement technique is based upon relaxation labeling. This method is a very general procedure that has been applied to a wide variety of problems. The purpose of the algorithm is to assign an unambiguous label (out of a set of N labels) to the data points. The labels, in effect, correspond to a symbolic representation of a data point. In the case of edge enhancement at a point, the labels considered correspond to a point belonging to an edge in the four possible directions. Once the initial probabilities have been assigned, the algorithm proceeds in an iterative and parallel fashion. The probabilistic labelings at each point are updated, based on the labels of its neighbors and the compatibility functions between labels.

Because of its explicit use of compatibility functions and larger neighborhood operations, the relaxation-based method for edge-enhancement is considered to be much more robust than most other edge-based techniques. However, due to the fact that the marine radar images at hand do not present clear edges, this method can converge only after numerous iterations. After many trials, it was found that even if relaxation labeling gives relatively good results, there is no way to determine if the algorithm is converging in an acceptable amount of iterations (or time). Moreover, even if the algorithm is converging, there is no way to determine when to consider the image good enough in a deterministic manner (this is needed for the final implementation aboard the ship). At this stage, we believe that the relaxation labeling method needs more work and research in order to determine its applicability to enhancing marine radar images. Due to time constraints, this method has not been selected for final implementation.

3.4 ALTC

There was no single algorithm which will segment the edges of the marine radar images. A combination of algorithms with various parameters was then developed: Average, Local Threshold, and Convolution (ALTC). This algorithm basically preprocesses the marine radar image using the previously chosen algorithms of the preprocessing section and combines the result in many possible ways with the original marine radar image. The results of this sequence are shown below:

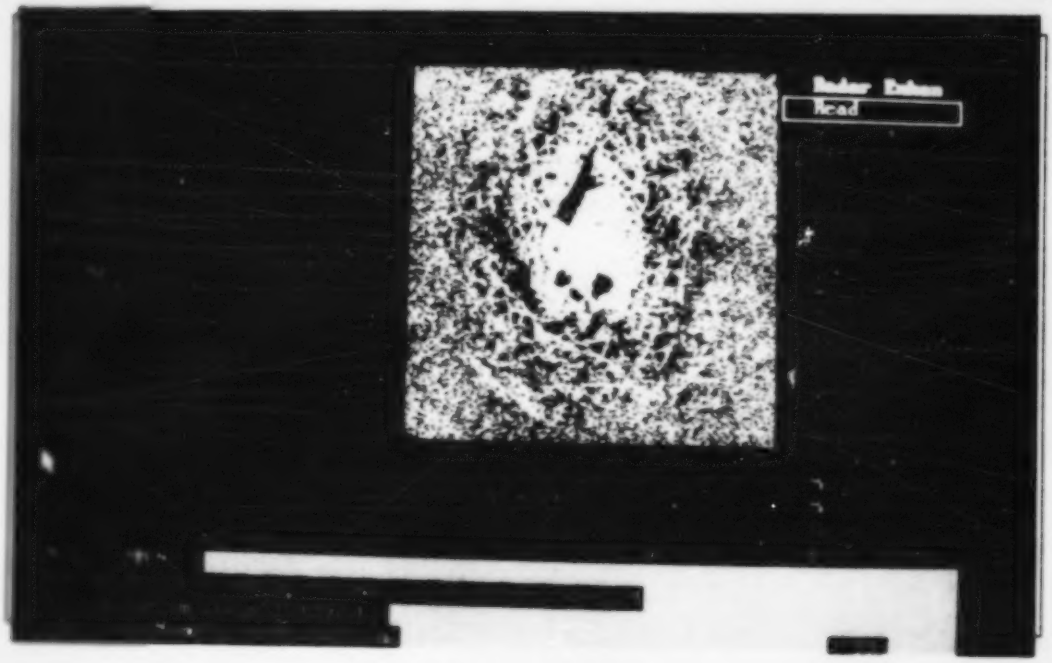

Figure 27 A marine radar image.

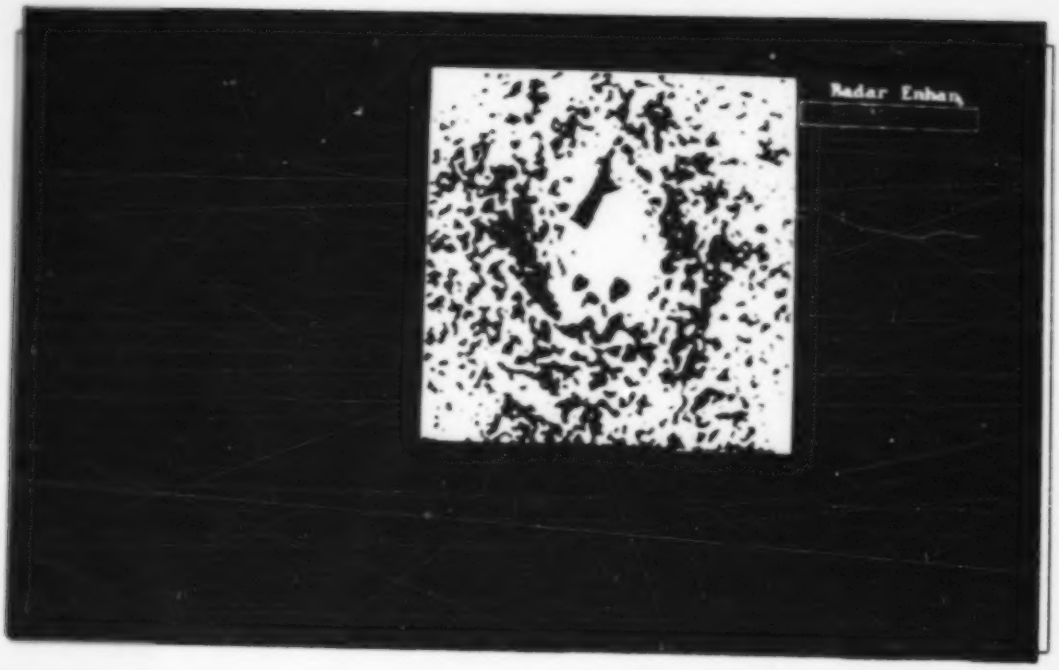

Figure 28 Average and local threshold.

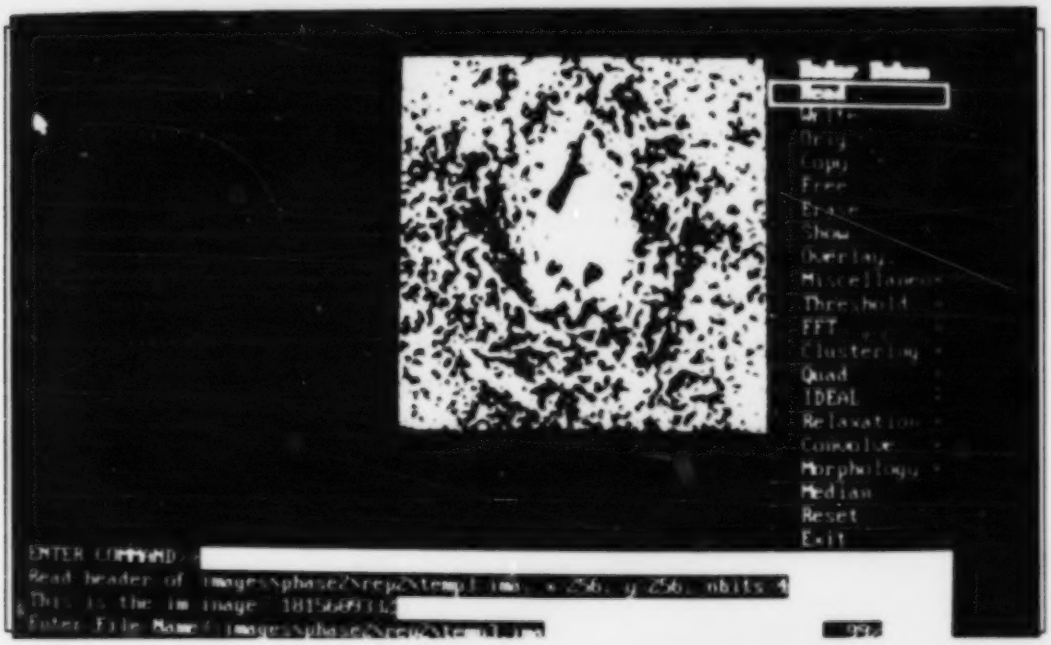

Figure 29 Combination of original and result.

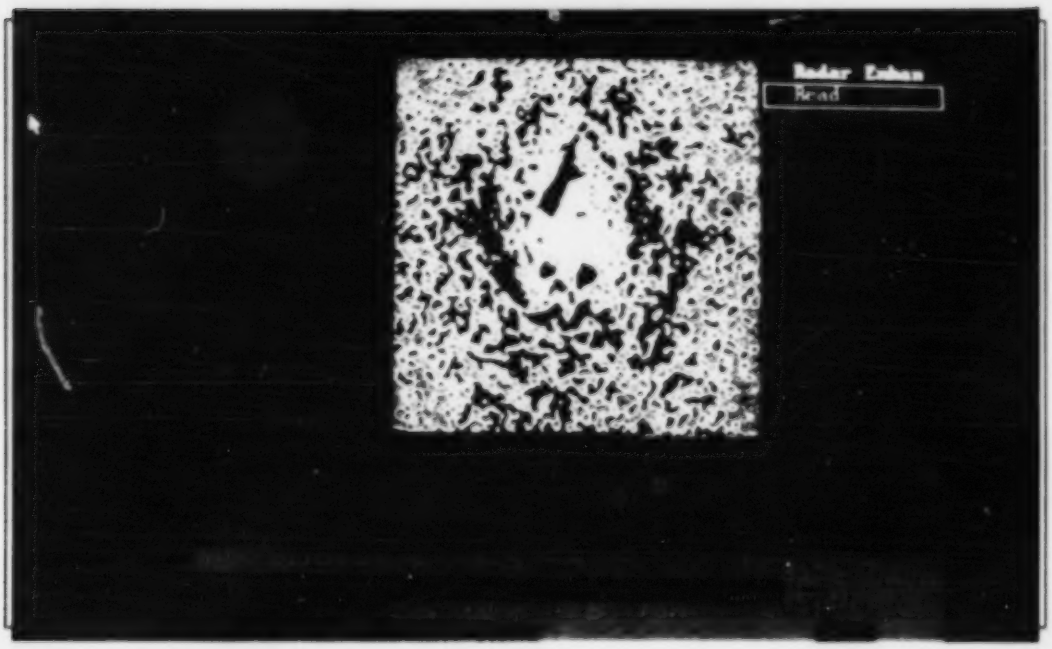

Figure 30 Edge enhancement of resulting image.

As seen above, this method enhances the existing ice floes appearance. The method has been applied on various marine radar images with successful results.

Example 1:

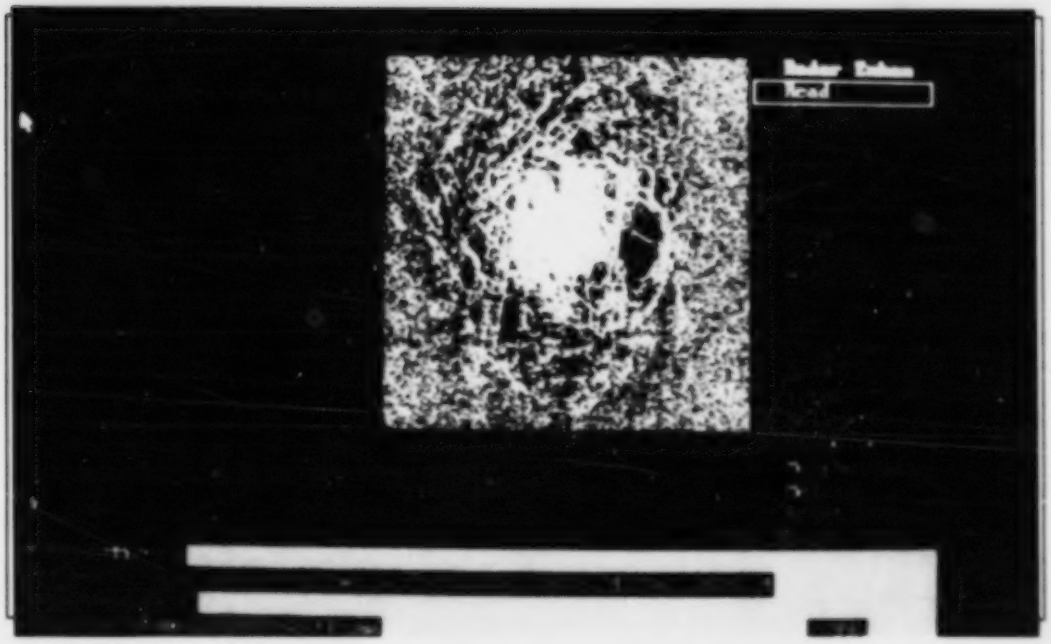

Figure 31 Original Image.

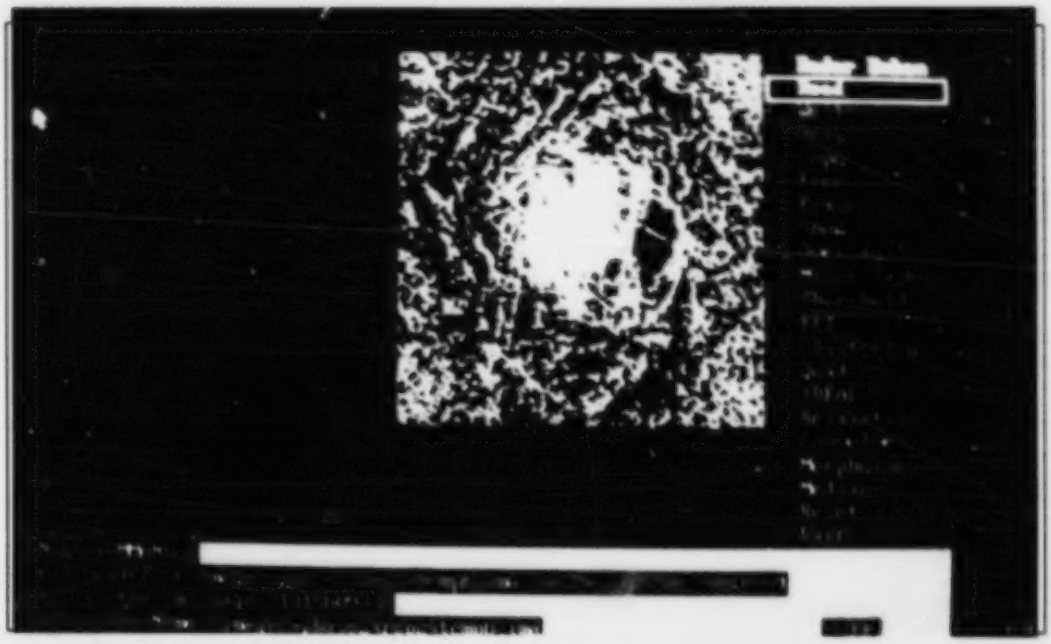

Figure 32 Resulting Image.

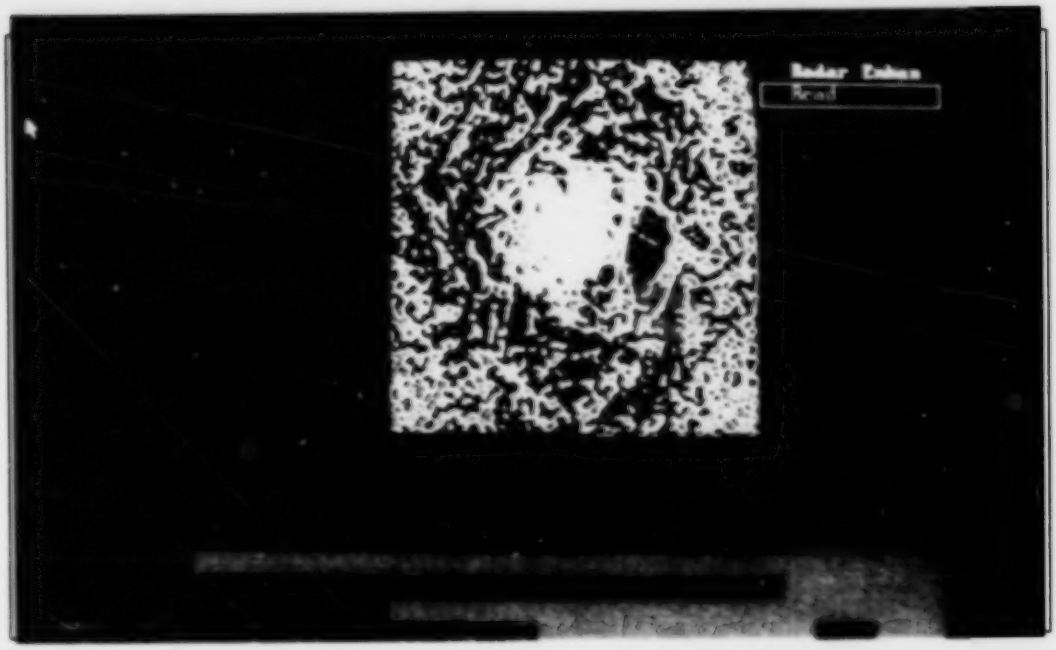

Figure 33 Edge enhancement of resulting image.

Example 2:

Figure 34 Original Image.

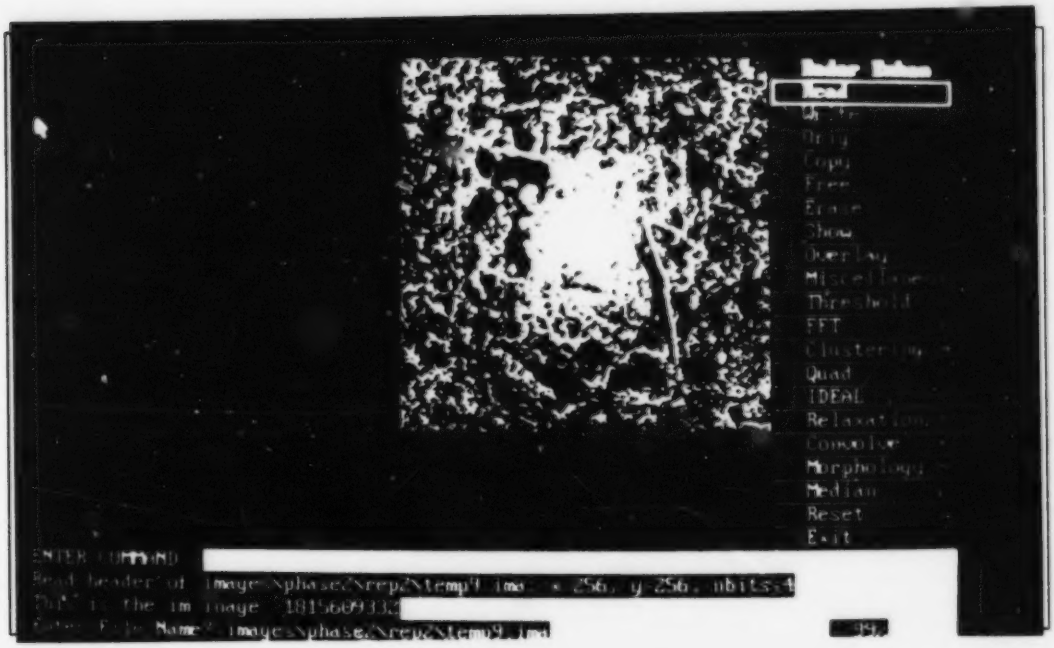

Figure 35 Resulting Image.

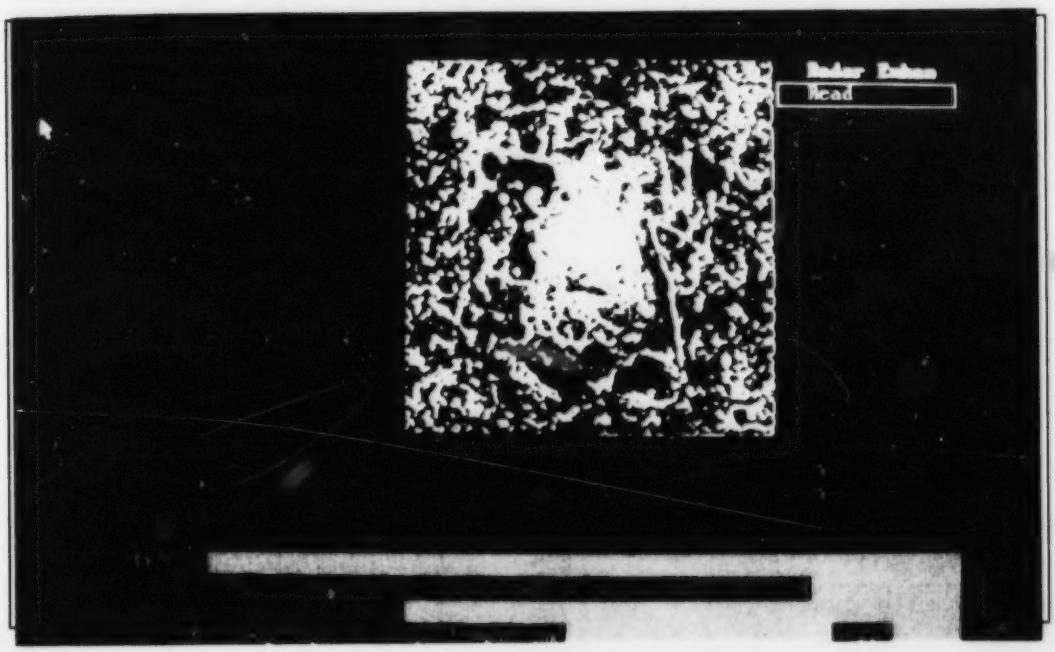

Figure 36 Edge enhancement of resulting image.

4. Selected Region based Techniques for Visual Enhancement

The purpose of this section is to explain and evaluate the region based techniques proposed for the enhancement of marine radar images as encountered in ice infested waters. The region based approaches have the advantage of defining discrete entities at the end of the treatment. These entities can later be used for automatic recognition with similar entities in the SAR image (after processing). The result of the application of region based techniques can also be used for the visual enhancement. It is the goal of this section to choose one method based on region treatment for final implementation.

4.1 Clustering

Clustering is a general scheme that groups together feature vectors in a feature space. The feature vectors are always grouped together under a minimum distance measure. Cluster seeking is an experiment-oriented algorithm because the performance of a given clustering algorithm is not only dependent on the type of image being processed but is also strongly influenced by the components of the feature vectors chosen to be analyzed. The best components to consider in the feature vectors can only be determined after extensive trials. In our case, we noticed that the components of the feature vectors were very dependent on the features in the radar image. This made it even more difficult to choose the right components of these vectors. To update a cluster, it is necessary to define a rule (measure of similarity) to assign feature vectors to the domain of one cluster or another. The measure of similarity that we considered is based on the euclidean distance of the feature vector at hand and the feature vector defining the center of gravity of each existing cluster.

The idea of clustering is very simple once a decision is made about the data to be clustered and the measure of similarity to be used; it suffices to group together the closest (minimum distance) feature vectors in the feature space. Many variations of the K-means and Isodata algorithms have been implemented and tested. No specific and deterministic way of choosing the components of the feature vectors was found. The results were very sensitive to noise. It is therefore concluded that the Clustering method needs to be pursued further in order to find good results. Due to time constraints, the method is then not chosen for final implementation.

4.2 Relaxation Labeling on Clusters

The idea of grouping certain pixels based on a similarity measure is the fundamental core of clustering methods. But clustering in general causes certain imposed shapes to appear in the image. In order to readjust the image or redistribute it in a more independent-of-shape fashion, a relaxation scheme on the clusters is employed. In relaxation, every pixel in the image has different labels with probabilities associated to them. The labels represent all the different clusters that one pixel can belong to, plus the possibility of being an independent pixel (considered to be noise in our case). As an initial guess for the relaxation labeling process, the result of the clustering algorithm is used. The center of gravity of a cluster has a high

probability of belonging to that cluster in question. As a point gets further from the center of the cluster to which it belongs, its probability of belonging to that cluster decreases and its probability of belonging to a neighboring cluster increases. The probability of belonging to a certain cluster is never zero at all points of the image in order to give rise to all possibilities. These probabilities are then updated at every iteration of the relaxation process based on a compatibility function.

Relaxation on clusters proved to be useful except that, as in relaxation for edge segmentation, the problem of convergence still remains. This algorithm needed more research and is not ready at this stage for final implementation.

4.3 Mathematical Morphology

This method essentially involves repeatedly expanding and contracting an image locally. This has the effect of removing small features by grouping together and unifying similar regions. This algorithm does not represent a final result by itself; it can, however, be used with clustering, relaxation on clusters, quadtree, and even relaxation on edges and curves. Because of the nature of the marine radar images, it was noticed earlier in the project that these images do not present well defined boundaries and therefore edge based techniques can not be applied directly to the raw image. Moreover, the marine radar images present many scattered echoes that tend to have undesirable effect on algorithms which are sensitive to noise. The expansion-contraction of the image has the effect of eliminating the scattered dots not supported by their neighbors.

At this stage, the algorithm needs an interaction with the user to know the sequence of contractions and expansions to be applied to the image. Its biggest problem is the fact that it is very hard to define an automatic manner to determine adaptively the sequence to be followed on a given image. Many trials have been conducted in order to pre–define a sequence that will be applied to the marine radar images. This sequence was, however, very difficult to find since it depends on the features actually present in a particular image. This algorithm is thus not selected for final implementation.

4.4 Quadtree

The quadtree method is a parallel splitting algorithm that can be applied on the marine radar images in order to get a more clear and better approximation of the dot clusters. Quadtree representation is based on a recursive subdivision of the image into quadrants. A quadrant can assume three possible states: empty, full or partially full. If the quadrant is full or empty, no further subdivisions are needed; the grey level of the quadrant is set to the average value of its intensity if full, or to zero if empty. In the case of a partially full quadrant (or partially empty), further subdivisions are needed. This procedure is carried until either all quadrants of the image are either full, empty, or a certain pre–specified resolution of the quadrants is reached. In the latter case the quadrant can be set to either full or empty. Practically speaking, we found that the small quadrants which reached the minimum resolution should be set to empty in order to give a better visual result.

Once the quadtrees are found, they can be chain traced (using contour following methods) and then the regions will be made available. This was the initial idea behind the development of this method. It turns out, however, that this method is very noise sensitive. The marine radar images that were obtained for this phase of the project were very noisy and the quadtree method did not perform well on them as opposed to the marine radar images obtained for phase I of the project. Nonetheless, it is clear now that the performance of this method will depend very much on the amount and type of noise that is available in the real marine radar images. This method is therefore not selected as a major method but can still be used because of its flexibility and memory requirements.

4.5 Region Splitting and Merging

Region merging is a process in which one begins with an image array and ends with a set of regions. Regions are merged together or pixels are merged into regions if the merging process does not affect considerably the uniformity of the two candidates of the merge. The decision of merging pixels is based on the comparison of the coming pixel with the distribution parameters of its neighboring regions in order to determine whether they are similar or not. If the pixel is similar (i.e does not modify considerably the distribution parameters of the region if it were included in the region), then the pixel is merged. Otherwise, the pixel is made into a region by itself. After each merge, the distribution parameters of a region, if modified, are updated.

The results obtained from the region merging algorithm confirm the fact that the marine radar images should be treated as images presenting clusters of dots rather than boundaries. It was noticed, however, that the performance of these algorithms are very dependent on the components of the feature vectors being considered, the shapes of the regions and the noise level or disturbance level. The image needs to be pre-processed keeping the region information intact while diminishing the effect of noise, shape, and feature vector on the algorithm. The Skeleton of regions seemed to be the best representation of a region under the above constraints.

A method was then implemented to pre–process the marine radar image using the "ALTC" set of algorithms described earlier. In order to keep as much information as possible of an ice floe but at the same time reduce the amount of data to treat a skeleton finding algorithm was developed. The region merging and splitting is then performed on the skeletons rather than on the actual regions. These regions are then either merged together if they respect pre–specified conditions, rejected, or kept intact. The outcome of this is a set of regions or clusters that are valid, meaning that they are geometrically defined, closed, and connected. This is the goal of all region based segmentation techniques.

For the visual enhancement end, the resulting image can then be edge detected (differentiated) in order to produce an overlay of edges to be used in conjunction with the corresponding SAR image. It is however important to notice here that a contour tracing algorithm is much better than edge detection. This is so because once the contour tracing is done, the regions are still valid and the result can be used for visual enhancement, region determination, or even later for automatic tracking. Some examples are shown below:

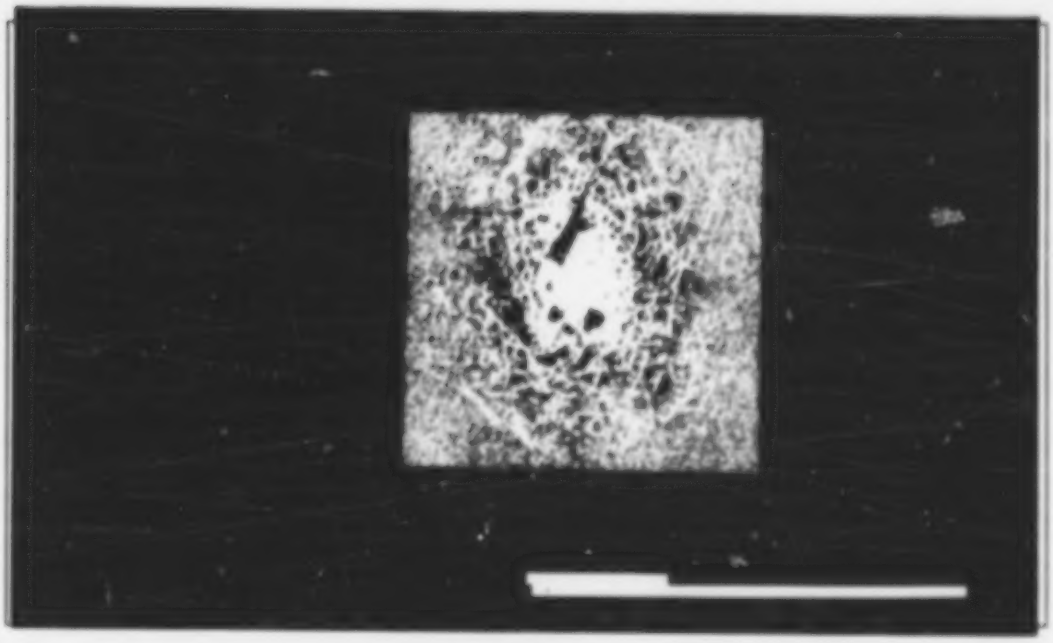

Figure 37 A Marine radar image

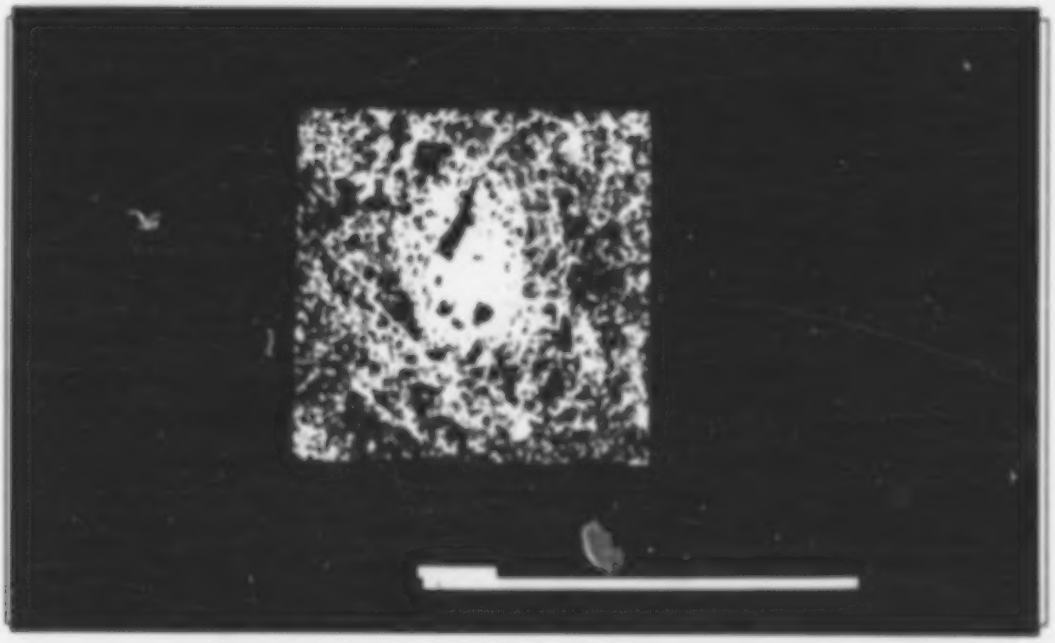

Figure 38 Skeletons

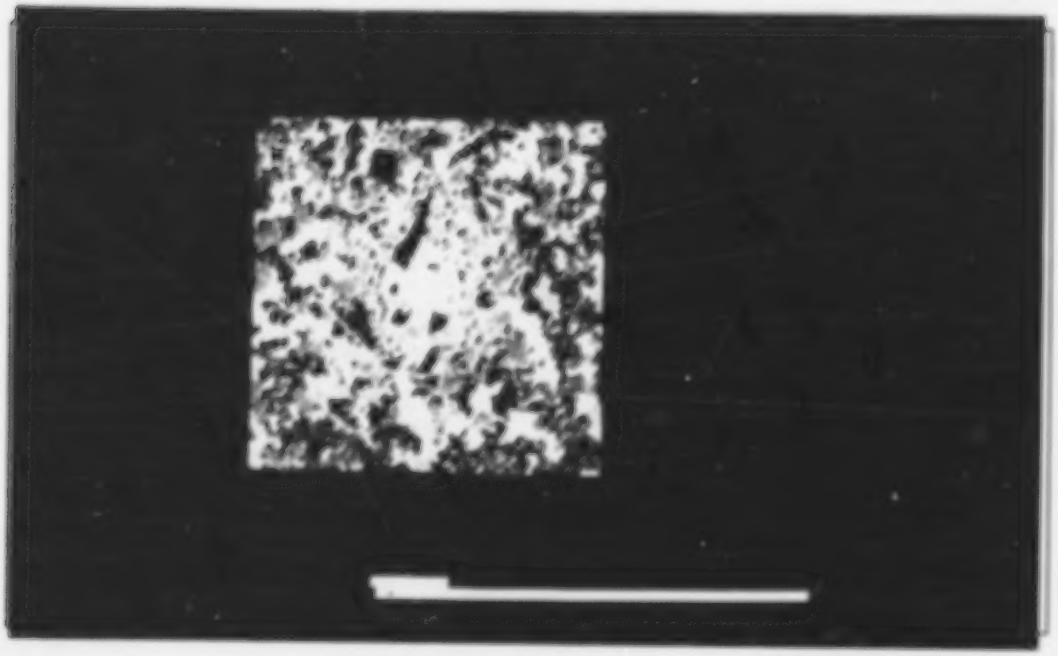

Figure 39 Regions

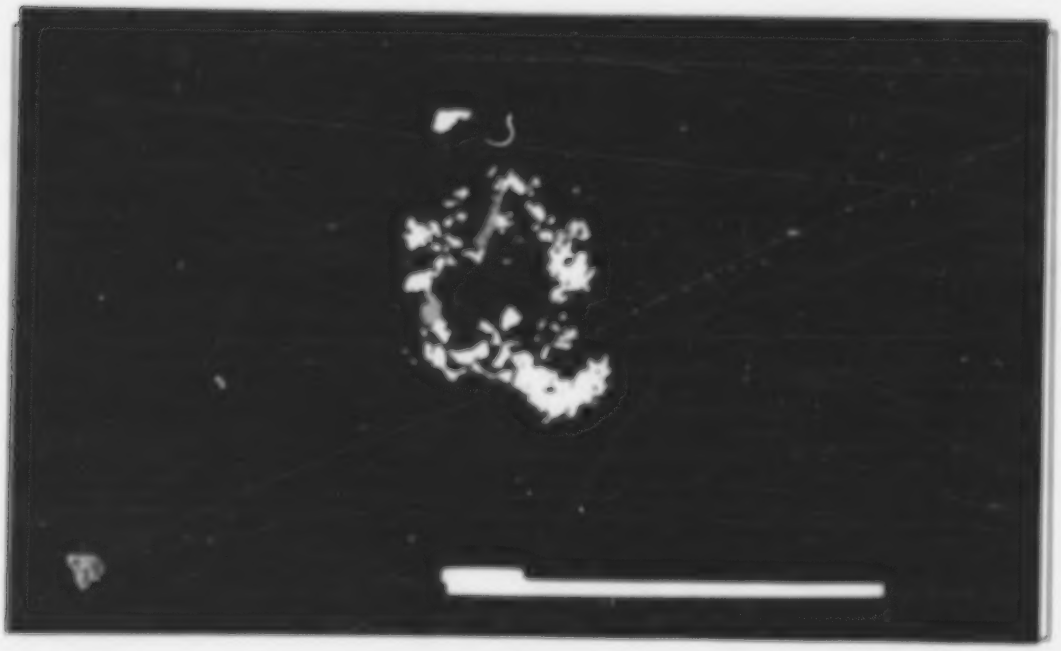

Figure 40 Selected regions

Figure 41 Contour tracing of some regions

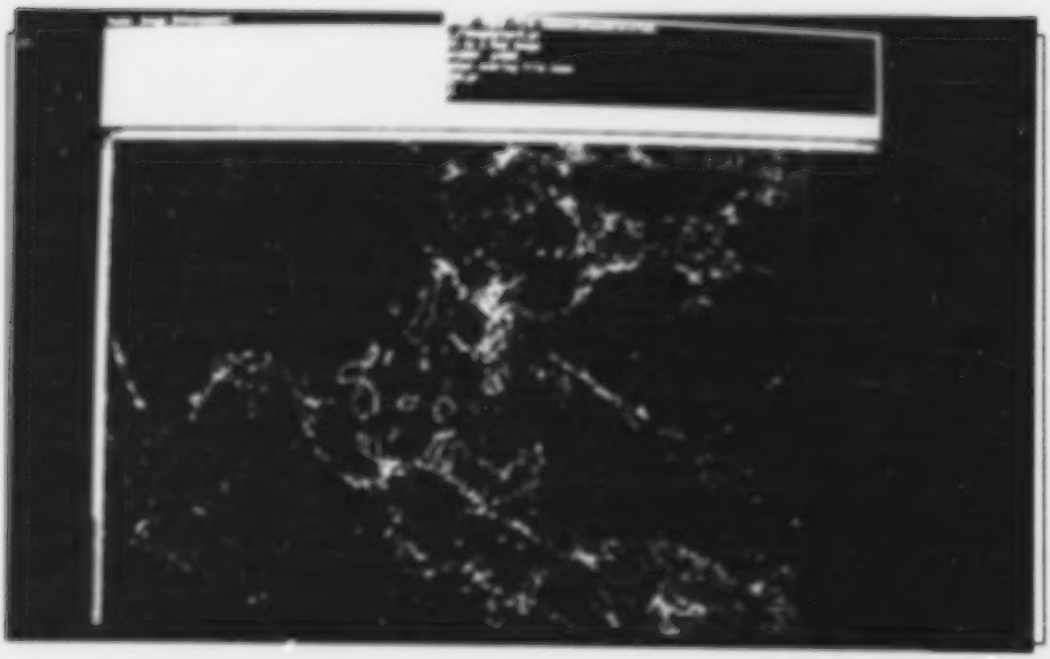

Figure 42 Overlay on SAR

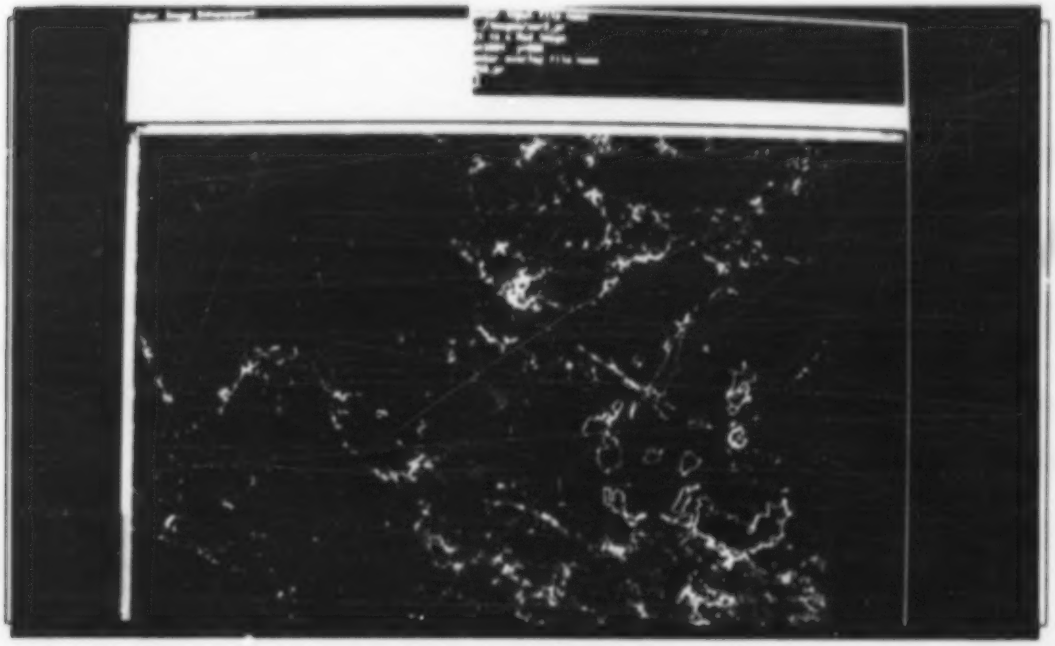

Figure 43 Fix

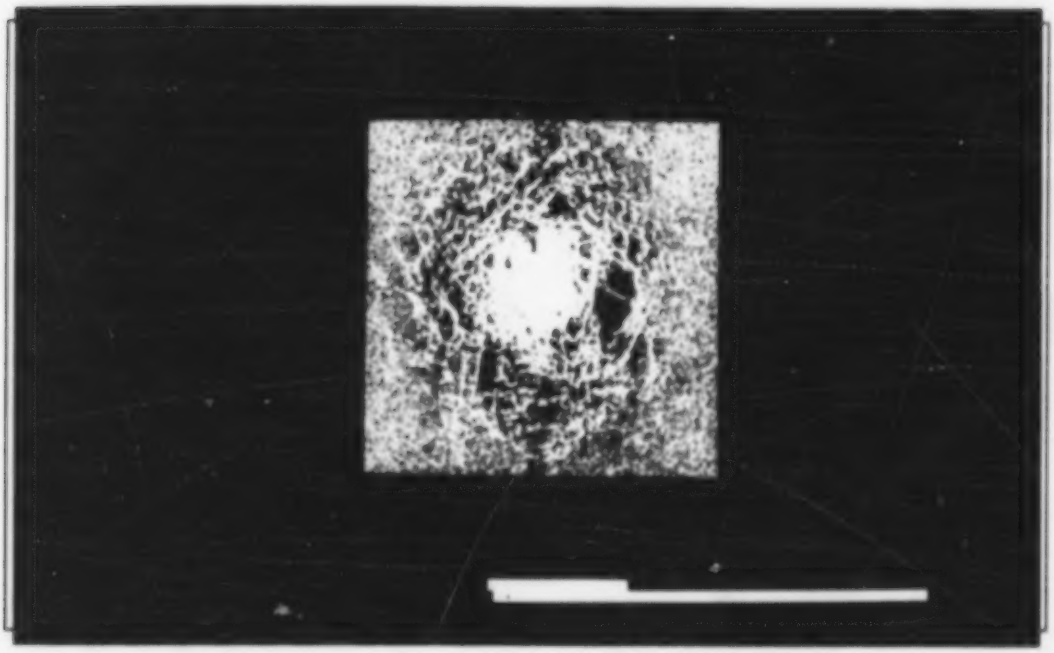

Figure 44 A Marine radar image

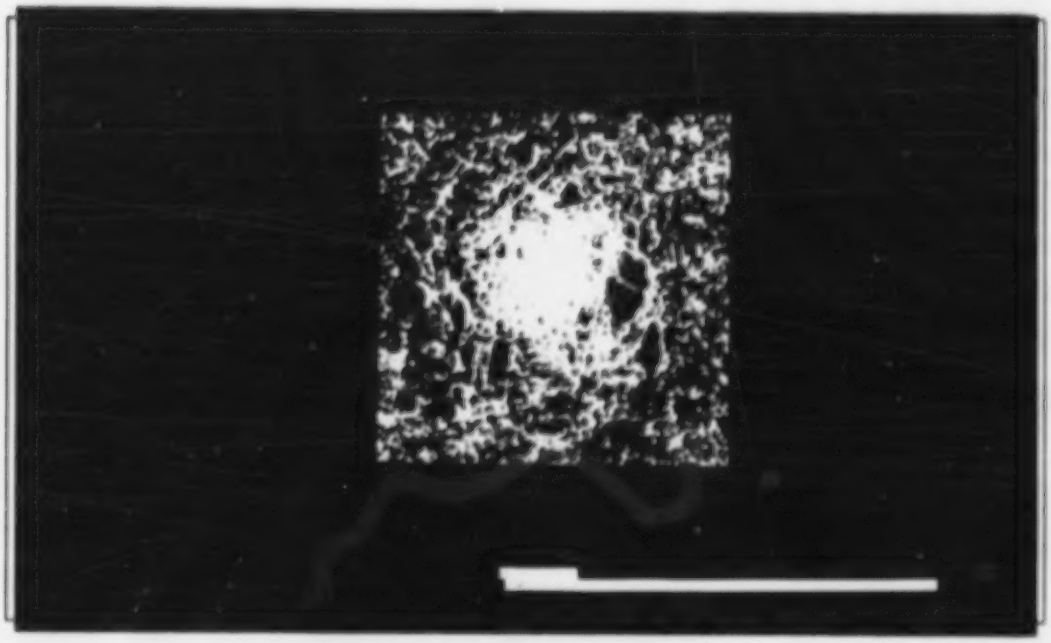

Figure 45 Skeletons

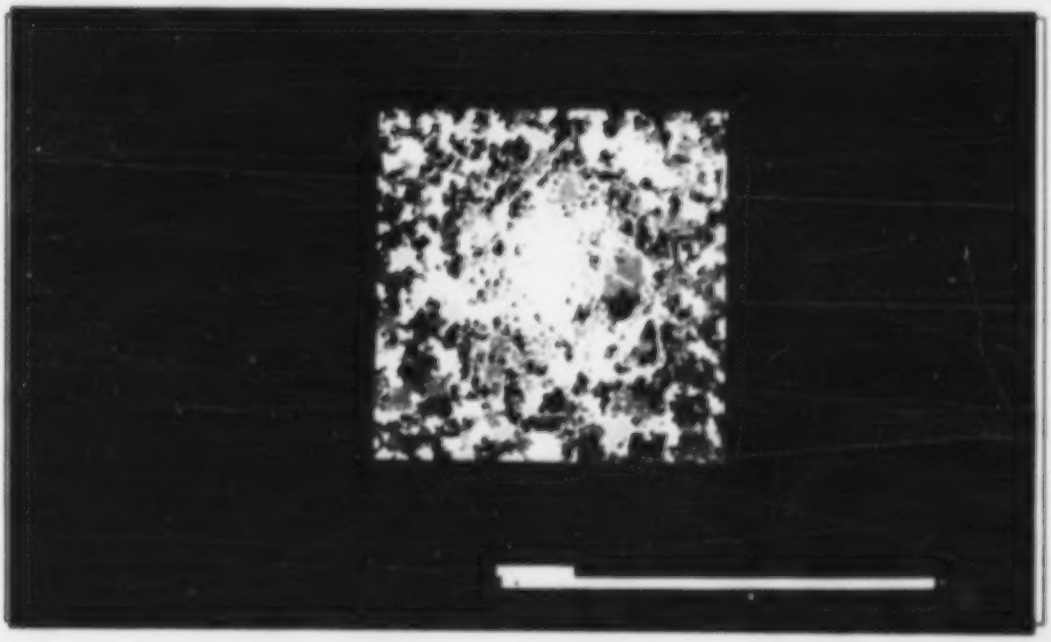

Figure 46 Regions

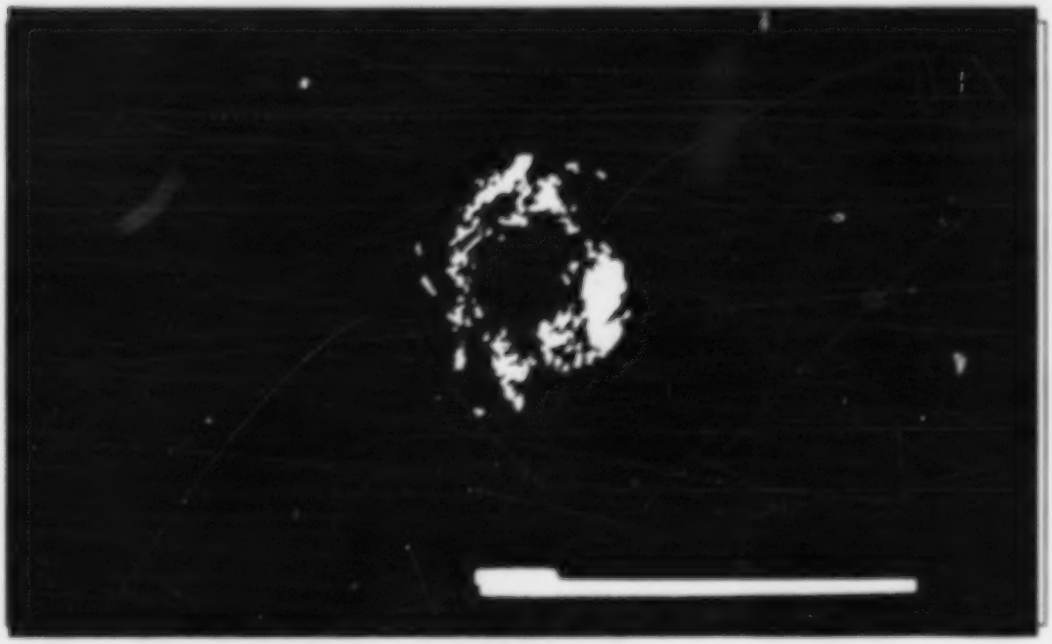

Figure 47 Selected regions

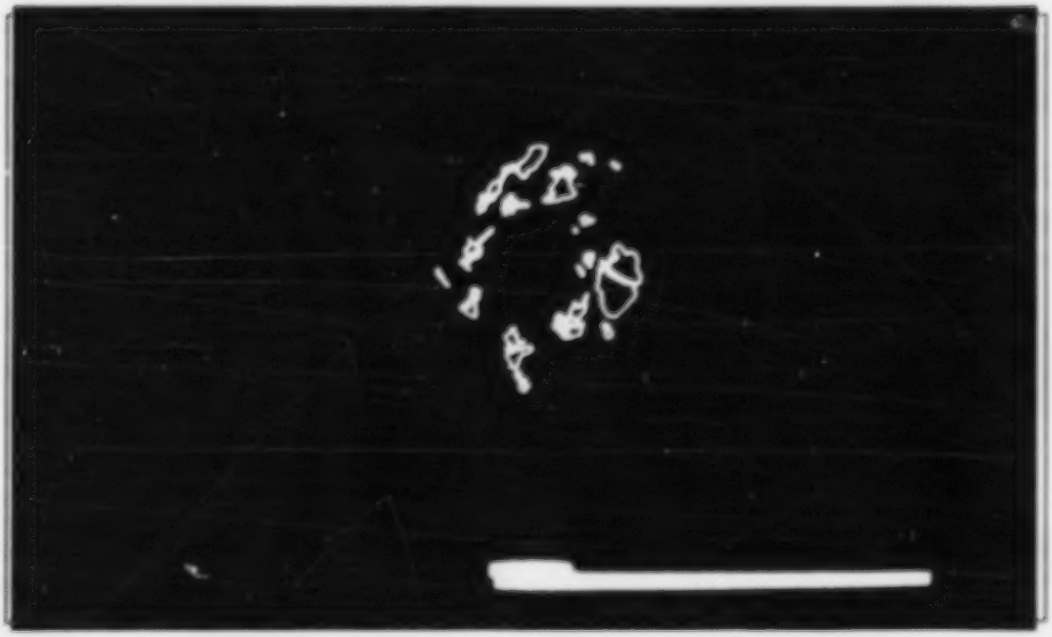

Figure 48 Contour tracing of some regions

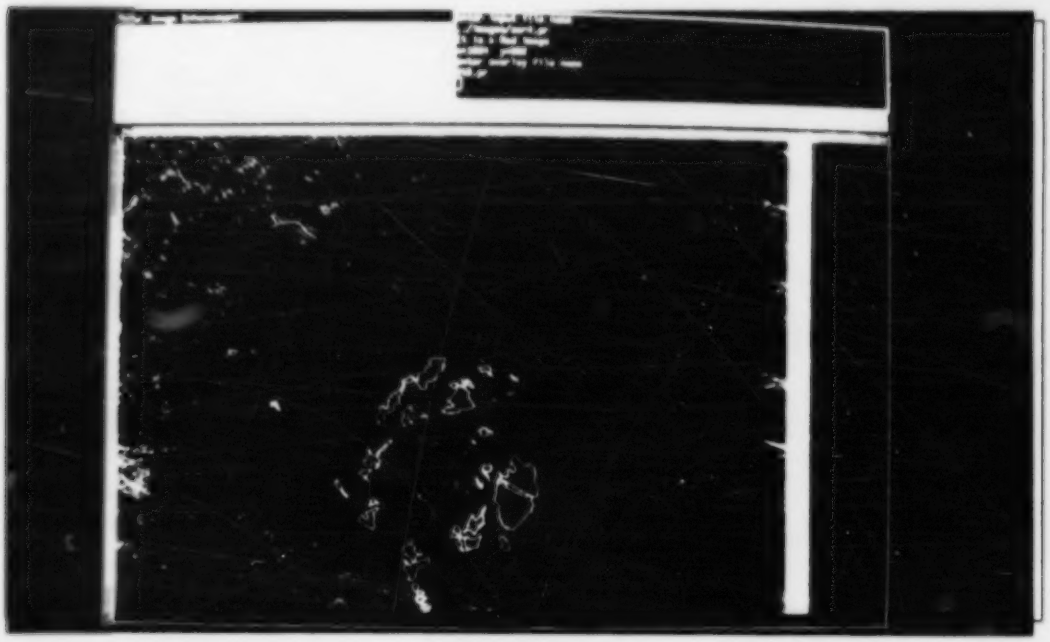

Figure 49 Overlay on SAR

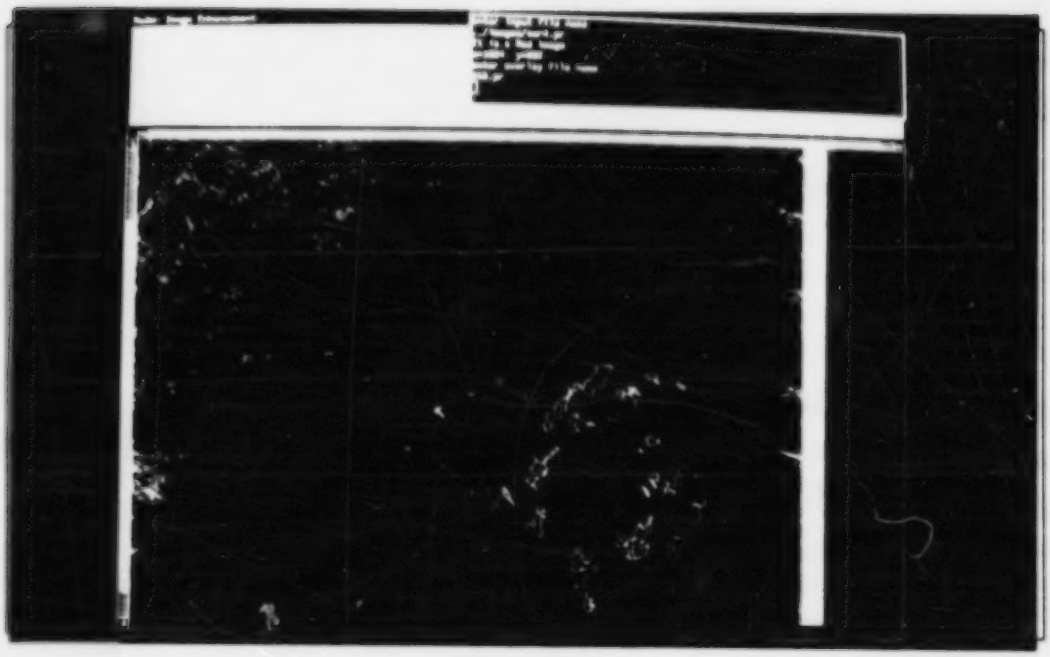

Figure 50 Fix

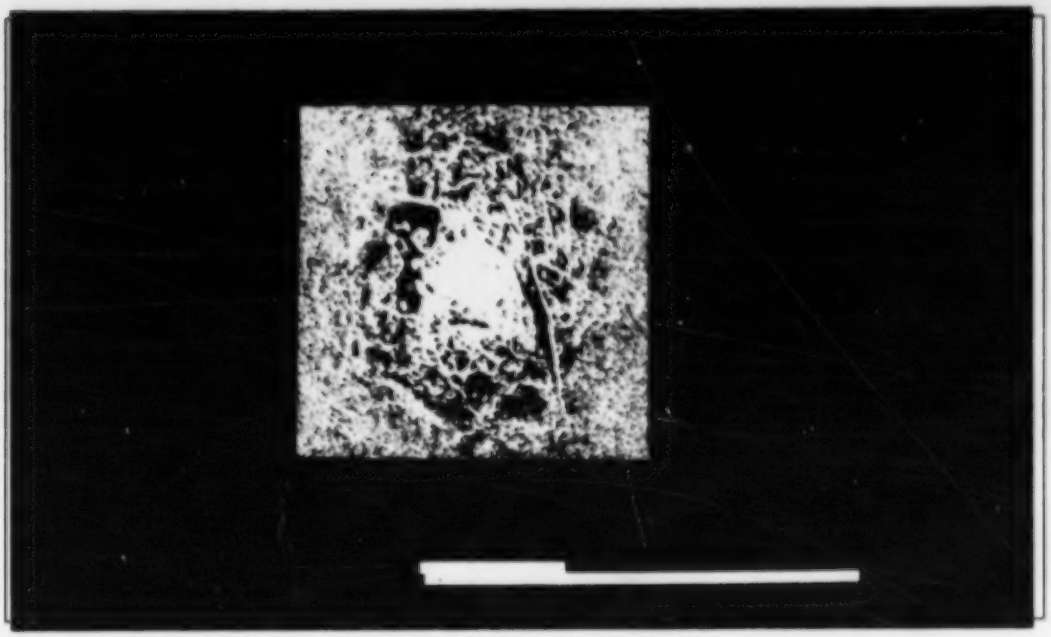

Figure 51 A Marine radar image

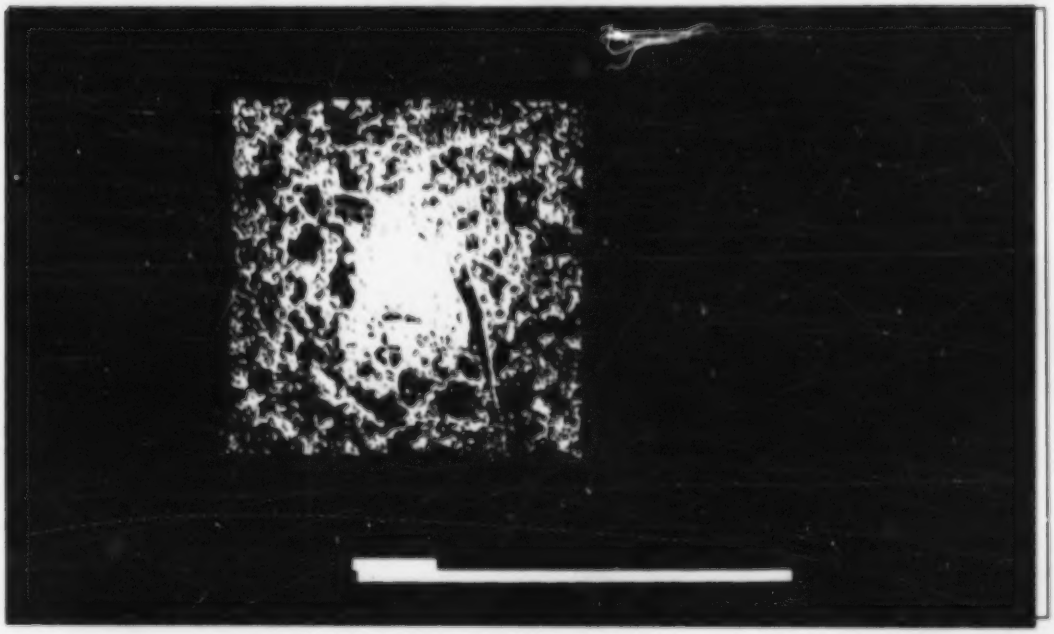

Figure 52 Skeletons

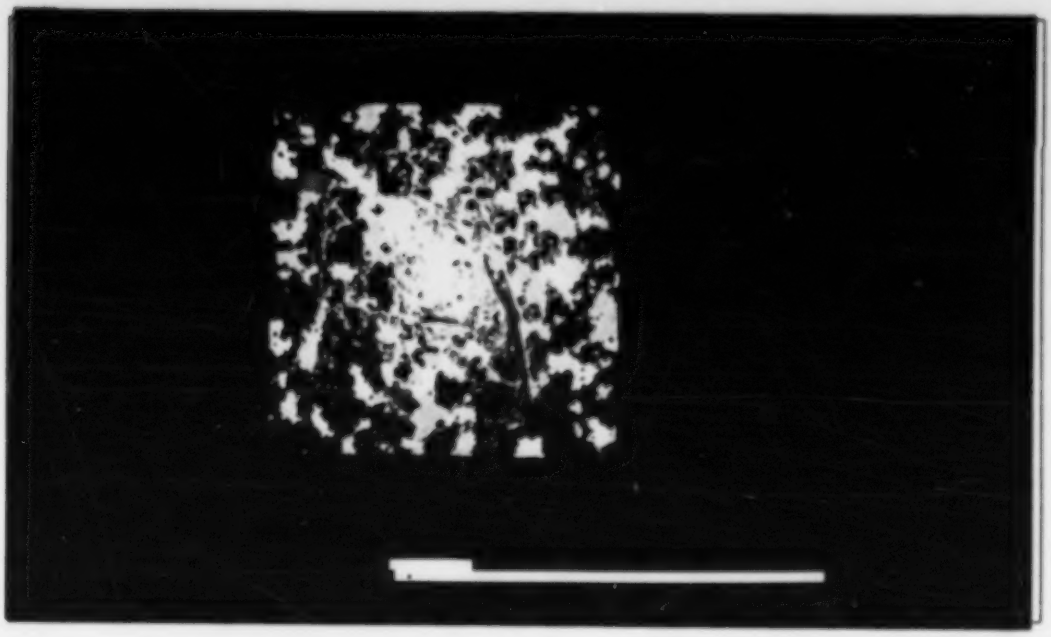

Figure 53 Regions

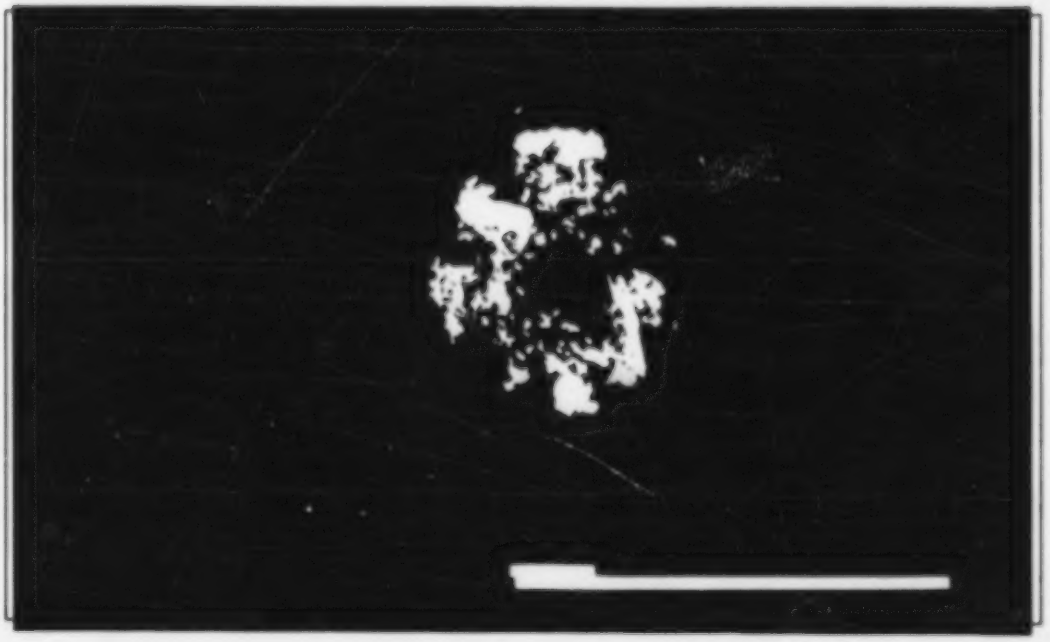

Figure 54 Selected regions

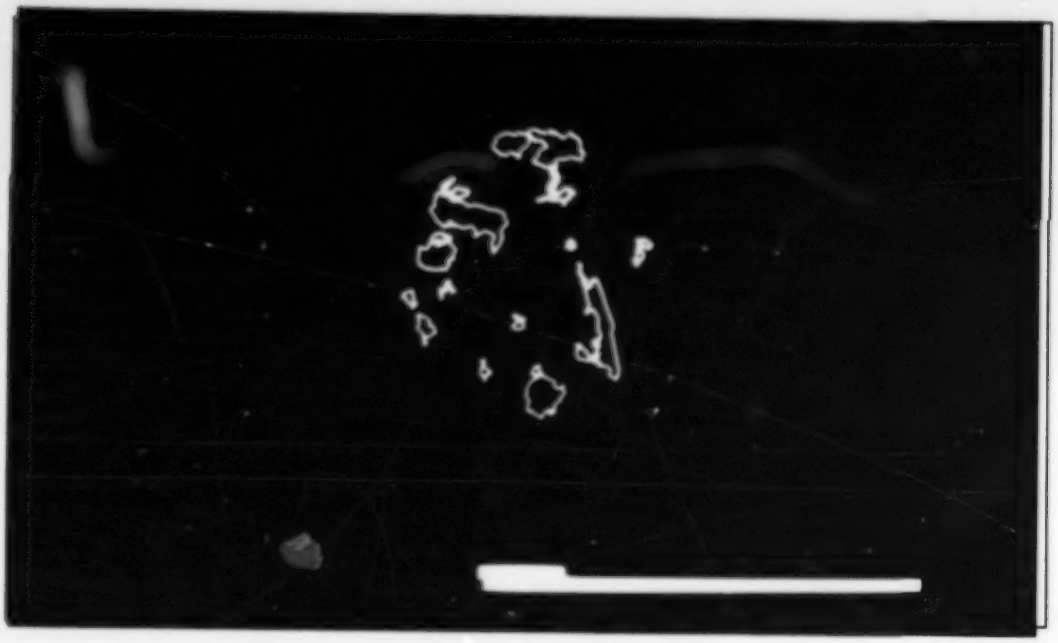

Figure 55 Contour tracing of some regions

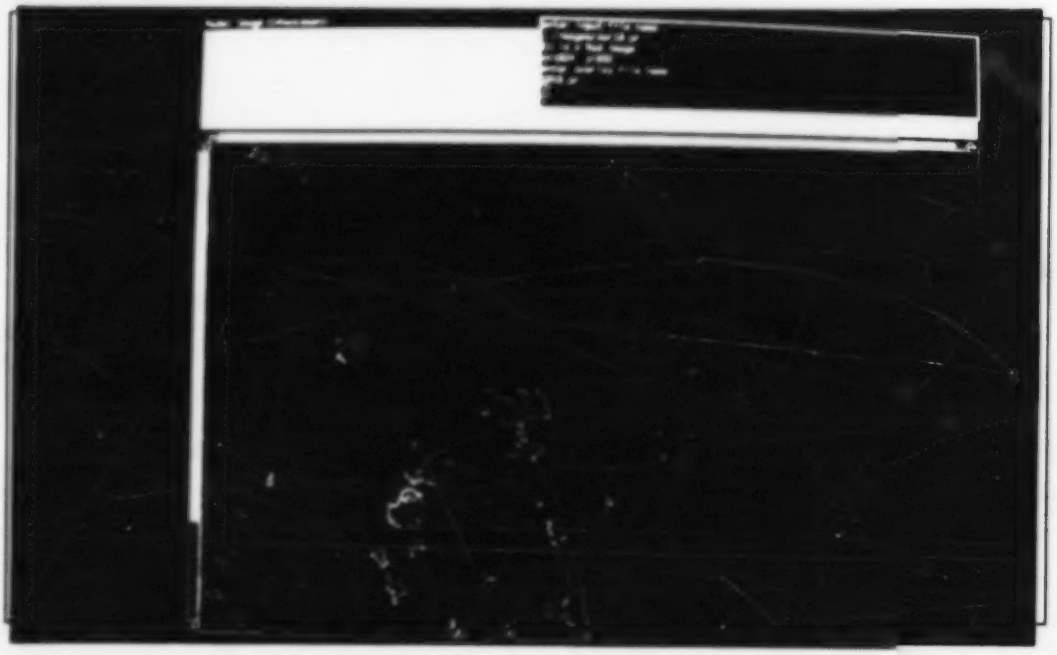

Figure 56 Overlay on SAR

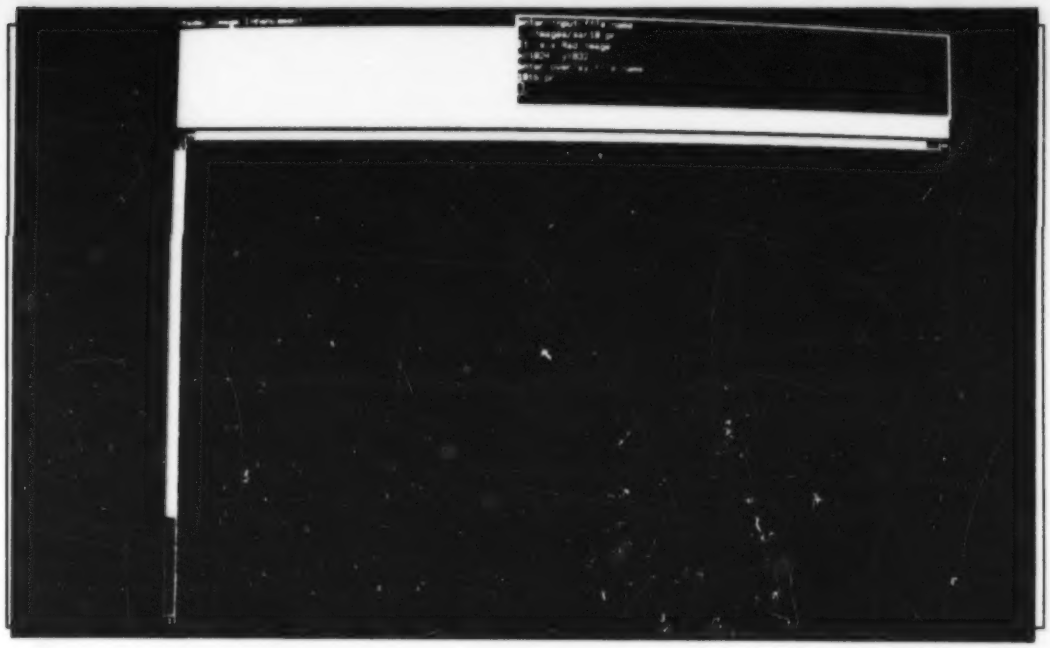

Figure 57 Fix

5. Selected Region based Techniques for Region Determination

The purpose of this section is to explain and evaluate the region based techniques developed in order to find and define valid ice floes in marine radar images. The region based approaches, in general, have the advantage of defining discrete entities (ice floes) at the end of the treatment. These entities can later be used for automatic recognition with similar entities in the SAR image. At this stage, one method has been chosen for final implementation for region based visual enhancement. It was also noticed during the evaluation of the enhancement and segmentation methods that the important features (in size, or shape) are the ones used by the human eye for the purpose of correlation. All efforts in this part of the project have, therefore, been concentrated toward finding and defining in a valid manner the "important" ice floes of the marine radar images. In this section of the report, we explain why a given region based method has or has not been chosen. we will, however, omit explaining the algorithms since they have already been explained in previous sections and reports.

5.1 Clustering

Many variations of the K-means and Isodata algorithms have been implemented and tested for regions determination. The results were very sensitive to noise. It was therefore concluded that the Clustering method is not very well suited for the ice floes determination in marine radar images.

5.2 Relaxation Labeling on Clusters

The relaxation labeling is applied on clusters in order to enhance the result of the clustering algorithm and make the found regions less dependant on any pre–defined shapes that could have been imposed by the choice of the feature vector components. The combination of both algorithms was very hard to tune properly because of the fact that there are many dimensions for clustering and many variable for relaxation. A general setting of the algorithm that is not very sensitive to noise and that is guaranteed to converge and generate regions that are corresponding to ice floes could not be found.

5.3 Mathematical Morphology

The performance of this algorithm is very dependant on the image being treated. The result is therefore, rather, unpredictable. For this main reason, this algorithm was not selected as a main one for the final implementation of region finding.

5.4 Quadtree

Once the quadtrees are found, they can be chain traced (using contour following methods) and then the regions will be made available. This was the initial idea behind the development of this method. It turns out, however, that this method is very noise sensitive. The marine radar images that were obtained for this phase of the project were very noisy and the quadtree method did not perform well on them as opposed to the marine radar images obtained for phase I of the project. Nonetheless, it is clear now that the performance of this method will depend very much on the amount and type of noise that is available in the real marine radar images. This method is therefore not selected as a major method but can still be used because of its flexibility and memory requirements.

5.5 Region Splitting and Merging

Region merging is a process in which one begins with an image array and ends with a set of regions. Regions are split from each other or merged together if the splitting or merging process does not affect considerably the uniformity of the two candidates of the split or merge.

The results obtained from the region merging algorithm confirm the fact that the marine radar images should be treated as images presenting clusters of dots rather than boundaries. It was noticed, however, that the performance of these algorithms are very dependent on the components of the feature vectors being considered, the shapes of the regions and the noise level or disturbance level. In other words, we can not rely on region merging, growing, or splitting being applied on the raw marine radar image without the operator's intervention. The image needs to be pre-processed keeping the region information intact while diminishing the effect of noise, shape, and feature vector on the algorithm. Again, the skeleton of regions seemed to be the best representation of a region under the above constraints.

After pre–processing the marine radar image and once the skeletons are found, they are disconnected under certain constraints in order to form regions. These regions are then either merged together if they respect pre–specified conditions, rejected, or kept intact. The outcome of this is a set of regions or clusters that are valid. Since it is not important to treat the region as a filled one (they are all filled), a contour tracing algorithm is then applied in order to generate the contours of the determined ice floes.

The outcome of the region determination algorithm is obtained at this stage. These regions can later be used for automatic tracking once the SAR images are treated in order to find and determine regions also. It was also recommended that the countours of the ice floe regions found from the marine radar image be overlaid on the SAR image. The results were good, since they helped the operator correlate both images. Various facilities for translating and rotating the overlay were developed to guide the operator in order to find a fix on the SAR image. The results that were shown in the previous section of visual enhancement can also be used as results of this section. The only difference is the fact that overlaying is not necessary here since the outcome of regions is supposed to be used for correlation with the regions to be found in the SAR image.

6. Developed Software

The software development included three major categories. The first is the user interface facilities, this included the development of a menu interface, and a key tree matcher. The goal of the user interface is not to make final user friendly package but rather develop the necessary tools for testing and demonstration purposes of image processing and manipulation algorithms. The second category of software developed is for image manipulation. This set of functions is for reading, writing, overlaying, scaling, rotating... marine radar images. The third category and most important one is the set of facilities developed for the image processing covering preprocessing, edge based segmentation, and region based segmentation techniques. It should also be mentioned that due to requirements of the image processing algorithms that were developed some software was ported to a SUN running UNIX BSD. This is mainly because of the memory requirements that could not be handled on a PC running DOS.

The following is a breakdown and an explanation of all developed software as presented in the menu structure.

Read: This allows the reading and displaying an image stored in the following format: xsize, ysize, number of bits per pixel, data.

Write: Save an image form the screen to a specified destination.

Copy: Copies an image from the original position to the result position of the screen.

Erase: Erases an image from one position of the screen. This does not free the memory taken.

Show: This places a certain image to one position of the screen.

Overlay: Overlays one image on another one and displays the result on a specified position.

Miscellaneous: A submenu that contains some miscellaneous facilities.

- Reflect: Reflect an image.
- Shrink: Shrink an image by a certain amount.
- Expand: Expand an image by a certain amount.
- Strengthen: Use all the available grey level values.
- Scale: Scale the intensity of an image
- Rotate: Rotate an image.
- Stats: Compute the histogram statistics of an image.
- Reverse: make the negative of an image.
- RangeNorm: Correct for the STC curve effect.
- XY2Polar: Cartesian to polar conversion.
- Polar2XY: Polar to Cartesian conversion.
- Clip: Choose only part of an image for treatment.
- Fine Zoom: Zoom with bi-linear interpolation.
- Coarse Zoom: Zoom using point duplication.
- Pan: Scroll an image.
- Aspect: Change the aspect ration of an image.
- LUT: Look-up table intensity enhancement.
- SelLUT: Look-up table intensity enhancement on a selected part of an image.
- Equal Hist: Histogram equalization for intensity enhancement.
- Sel. Eq. Hist: Histogram equalization for intensity enhancement on a selected part of an image.
- Chain Trace: Chain trace an object in an image.
- Treat: averaging with local thresholding.
- Combine: Combines both images on the screen (original and result).

Threshold: A submenu that all thresholding algorithms.

- Arbitrary: Threshold at an arbitrary value.
- Average: Threshold at the average of the image.
- Otsu: Implementation of the Otsu threshold algorithm.
- Adapt 3x3: Threshold adaptively on a 3x3 window basis.
- Adapt 5x5: Threshold adaptively on a 5x5 window basis.

LowAdapt 3x3: Threshold adaptively on a 3x3 window basis using a low pass filter.

LowAdapt 5x5: Threshold adaptively on a 5x5 window basis using a low pass filter.

Fft: A submenu that contains all FFT related algorithms.

FFT: Implementation of the FFT algorithm.

Inv FFT: Implementation of the inverse FFT algorithm.

Filter: Applying a filter in the frequency domain: low, high, and band pass filters.

Clustering: A submenu containing all clustering related algorithms.

Cluster: Form the clusters tree of an image.

Visittree: Visit the tree of clusters.

Kmeans: Implementation of the K-means algorithm for clustering.

Isodata: Implementation of the Isodata algorithm for clustering.

Quad: A submenu containing all quadtree related algorithms.

VarQuad: Set all variables concerning the Quadtree algorithm.

Quadtree: Form the Quadtree of an image.

LevelQuad: Display the quadtrees of an image level by level.

Pyramid: Implementation of the pyramid structure algorithm of an image.

Level: Display the pyramids on an image level by level.

Regm: Implementation of a region merging algorithm based the scan line data.

Zoomquad: Quadtree applied on different parts of an image.

Tracing: A submenu containing all tracing and a moment computations algorithms.

Moments: Compute the moments of area of a valid object.

Feature: Find the unusual features of a valid object.

Rotate: Rotate a valid object.

Translate: Translate a valid object.

Scale: Scale a valid object.

trace: Chain trace the countour of a valid object.

Relaxation: A submenu containing all relaxation labeling related algorithms.

Clrelax: Relaxation labeling on a set of clusters of an image (region based)

Intrelax: Relaxation labeling on the intensities of an image (region based)

4-Label-Relax: Relaxation labeling on the edges of an image with four directions.

8-Label-Relax: Relaxation labeling on the edges of an image with eight directions.

Interactive: Relaxation labeling on edges in an interactive manner for convergence.

Convolve: A submenu containing all convolution related algorithms.

Conv. 3x3: A submenu of 3x3 window convolution.

Laplacian: The Laplacian 3x3 detector.

BiLaplacian: The BiLaplacian 3x3 edge detector.

Sobel-N: Sobel edge detector in the North direction.

Sobel-NE: Sobel edge detector in the North–East direction.

Sobel-E: Sobel edge detector in the East direction.

Sobel-SE: Sobel edge detector in the South– direction.

Sobel-S: Sobel edge detector in the South direction.

Sobel-SW: Sobel edge detector in the South–West direction.

Sobel-W: Sobel edge detector in the West direction.

Sobel-NW: Sobel edge detector in the North–West direction.

Sobel-XY: A global Sobel edge detector.

User-Defined: Application of a user definable edge detector.

Average3x3: A low pass average convolution based on a 3x3 window.

Zeros: A zero finding algorithm that needs to be applied after the Laplacian for edge detection.

EdgePreserve: Edge preserving averaging of the image.

Conv. NxN: A convolution of an nxn size window over the image.

Median: The application of a median filter over the image.

Lg: The application of the Laplacian of a Gaussian over the image.

Morphology: A submenu containing all morphology related algorithms.

Erode: Application of a morphological erosion of an image.

Dilate: Application of a morphological expansion of an image.

Opening: Dilate and erode an image.

Closing: erode and dilate an image.

X-Erode: Application of a morphological erosion in the diagonal directions.

X-Dilate: Application of a morphological expansion in the diagonal directions.

X-Opening: Dilate and erode an image in the diagonal directions.

X-Closing: Erode and dilate an image the diagonal directions.

O-Erode: Application of a morphological erosion around each pixel of an image.

O-Dilate: Application of a morphological expansion around each pixel of an image.

O-Opening: Dilate and erode around each pixel of an image.

O-Closing: Erode and dilate around each pixel of an image.

Adaptive-Erode: Erosion using the edge preserving smoothing algorithm.

Adaptive-Dilate: Expansion using the edge preserving smoothing algorithm.

Adaptive-Opening: Expansion and Erosion using the edge preserving smoothing algorithm.

Adaptive-Closing: Erosion and Expansion using the edge preserving smoothing algorithm.

Exit: exiting the program.

All the above facilities have been implemented on a Dos based computer. However, due to the limited amount of memory under Dos, and after many trials to solve this problem by developing some memory management facilities, a decision was made to port some of the code to a Unix based system (Sun). A small user interface was developed using Suntools as a windowing environment. The miscellaneous facilities as well as some necessary algorithms were also ported on the Sun. More software was then developed on the Sun system for various implementation of algorithms. These facilities included:

Skeleton: This formed the skeletons of the dark regions of an image.

Grow: Growing skeletons to form regions that could intersect.

Split: A region splitting algorithm based one some statistics of an image.

Merge: A region merging algorithm based on some statistics of an image.

Trace: A chain tracing algorithm.

Overlay: An overlay processing facility.

The above facilities on the Sun constitute the core of the region based segmentation techniques.

The software developed in order to demonstrate the effectiveness of using image processing techniques explained above was all developed by Cimmetry Systems and was mostly written in

the "C" programming language. The source listings of the different image processing algorithms are included in appendix "B". Some graphics facilities were written in Assembler in order to speed up the displaying process. The software was not designed to be a commercial package, but was, rather, developed for testing and choosing the different algorithms.

The Software is divided in two packages: the first runs under the Dos operating system and requires a VGA graphics card and a math co-processor. The second runs under Unix on a Sun machine and needs the Suntools windowing system. A copy of the software is delivered with this report.

7. Conclusion

In the final report of Phase V of the Shipboard Ice Navigation Support System (SINSS) one recommendation put forward by Canarctic Shipping Ltd and the Transportation Development Centre was to investigate the use of signal processing techniques in order to improve the quality of the marine radar images. To this end, Cimmetry Systems has developed and tested a wide variety of image processing algorithms. Canarctic Shipping Ltd was subcontracted for the supervision and recommendation during the development of this project. The reports submitted by canarctic Shipping Ltd are included in Appendix "A".

The goal was to choose a set of algorithm for final implementation aboard the ship for: preprocessing of marine radar image, edge based segmentation techniques, and region based techniques. The preprocessing can be used for two possible ends: First, this set of algorithms can be applied on the marine radar image in order to enhance the overall look of the image. Second, the preprocessing algorithms are necessary for any kind of edge based or region based segmentation techniques.

The idea behind the segmentation of the marine radar image was to find and define specific regions of the image. Once these regions are found, enhancement can be made for the visual content and also more region extraction can be used for the pattern matching that takes place between the marine radar image and the SAR image. Two major methods of segmentation have been studied and test, namely, edge based and region based segmentation techniques.

The edge based segmentation, in general, did not show good results because of the fact the marine radar image is not made of edges but rather of clusters of dots. Nevertheless, it was noticed that some kind of edge enhancement is desirable because the ridges present in the marine radar images may sometimes be very important if not necessary for the visual marine radar versus SAR correlation. Some algorithms have been retained for this end of edge enhancement.

Because of the nature of the marine radar image, region based segmentation shows good results, both for the visual enhancement as well as the region finding and determination for a possible automatic correlation with the corresponding marine radar image. The region based segmentation algorithms are more robust and showed better results than the edge based ones.

A summary of the chosen algorithms after many trials during this phase of the project is given below:

Preprocessing Methods.

Many preprocessing methods have been developed both for visual enhancement, preparation for edge based segmentation and preparation for region based segmentation. The conclusion was that edge preserving smoothing along with median filtering were yielded to the most acceptable results both for visual enhancement (this includes enhancement for edges) as well as preprocessing for edge based segmentation techniques. On the other hand, mathematical morphology and median filtering yielded to the best results of preprocessing for region based segmentation techniques.

Edge Based Methods.

No one algorithm showed acceptable results for edge based segmentation because most of the developed techniques were very noise sensitive. This is generally so for edge based segmentation because edge finding involves differentiation which in its turn increases the amount of noise in an image. It was found, however, that an Average filtering with Local Thresholding followed by a Convolution or edge detection (ALTC) has generated good results. This set of algorithms was preceded by some preprocessing as explained previously.

Region Based Methods.

There two goals behind the application of region based segmentation to the marine radar image, namely, visual enhancement as well as region finding and determination. The goal for region finding and determination is more for automatic tracking since the regions would then be valid entities of which moments and other descriptions can be computed. A method based on skeleton finding followed by region splitting and region merging showed good results for defining and determining the regions or ice floes of the marine radar image. These techniques are applied after the preprocessing needed for region based segmentation. After the application of this set of algorithms, the important or most striking ice floes of the marine radar image become valid entities. In the case of segmentation for automatic tracking, the marine radar treatment is completed at this stage and a similar treatment should be applied to the SAR image. The same set of algorithms can not be applied to the SAR image since these images are very different in nature. In the case of visual enhancement based on region determination, a countour tracing algorithm was implemented in order to define the edges of the found regions. These edges can then be overlaid on top of the SAR image. This method has shown good results for helping the operator correlating visually both images.

8. References

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Appendix A: Technical Reports from Canarctic Shipping

The following appendix contains the comments and technical reports submitted by Canarctic Shipping during the course of the project.

Radar Image Enhancement Project
Visit Report (1st visit)

Scope

This report relates to the Canarctic visit to Cimmetry in Montreal on the date of July 4th., 1989. One new enhancement method (combination of algorithms) was demonstrated using the radar/SAR image pairs collected in the fall of 1988.

Description

Discussions were held about the difficulties experienced in decoding the images recorded on TK-50 tapes transmitted by Intera. The tapes had been recorded on a tape unit slightly out of alinement and therefore some adjustments to Cimmetry's tape drive had to be made before the image files could be read. Once the files were transferred, a period of no less than one month was spent decoding the images, the format specifications supplied by Intera being erroneous. Enhancement software developments resumed as soon as the images were decoded, however at least one month of valuable project time was lost.

The decoded radar images were very noisy, with little resemblance to the images normally displayed on the MARINE-VUE system on board the ship. The causes and implications of bad radar images were discussed and it was decided to investigate the matter further with recommendations to be given at a later date. The SAR imagery appeared to be adequate and corresponded to the images that are normally displayed on the STAR-VUE system.

The method tested on the radar images is a combination of QUAD TREE and REGION MERGING. The method readily defined regions that were visually identifiable on the original image. The final result was shown as a combination of the original and processed image.

The usefulness of the method was rapidly reduced in the periphery of the image, where substantial noise made the software define regions that did not relate to existing features in the original image. The net effect of the noise at far range, was to confuse the software to a point where the results of the enhancement cannot be used. In the centre of the image however, the method was quite successful at identifying features that are recognisable on the radar image.

Several image manipulation utilities were demonstrated to assist the process of image analysis. The processing algorithms, as implemented on the IBM Pc compatible computer were so slow, that the images were divided in four to reduce the processing time. Even with the reduced image size, at least 15 minutes was required for the processing of an image.

Recommendations

Following this meeting, a number of recommendations were submitted to Cimmetry:

A) Special attention should be given to the quality of the radar images used for the development of enhancement algorithms. Only images that comprise clear features should be used for the development.

B) All known factors contributing to the degradation of recorded radar images were investigated. A list of the MARINE-VUE settings for all the recorded images was transmitted to Cimmetry, along with the correction curves of the video processing unit built by Intera. All efforts should be made to restore existing images to their original condition before entering the video processor, using the given data.

C) Due to the bad quality of the recorded images, only the central part of the image should be used for enhancement developments until better images can be found.

D) Some effort should be made to find alternate processing methods aimed more at enhancing floe features than the total image.

E) An overlay procedure should be developed to transfer enhanced features to the SAR image.

Radar Image Enhancement Project
Visit Report (2nd visit)

Scope

A short unscheduled visit to Cimmetry allowed Canarctic to assess the progress of the project. As a result of this assessment and out of mutual agreement, the second scheduled visit was defered until the end of the project, where the final methods could be demonstrated and a clear proof of concept demonstrated. The last visit to Cimmetry occurred on October 11, 1989, at Cimmetry's offices in Montreal.

Description

As a result of the recommendations from the first visit, new algorithms were developed to extract features from the radar images. The new method does not attempt to extract features that are difficult to identify visually, but concentrates on features that are clearly present in the radar image. The results of this new method are presented in the form of an overlay that can be moved to the SAR imagery for comparison. Because of the high processing overhead, the processing algorithms and the images were transferred on a SUN station. Also, because of the limited time available for the demonstration, most of the results were prerecorded. Real time processing was limited to a few examples only.

The morning was spent experimenting with the different radar and SAR images stored on the system. The emphasis was put on finding the most significant image pair in terms of correlation difficulty. Several pairs were identified as benefiting the most from the enhancement algorithm developed, and were prepared for demonstration.

The new overlay facility was a turning point in the direction of the project, and the significance of its impact was not understood or foreseen until it was actually implemented and tested. During the morning preparations, several modifications were suggested to complement the overlay manipulation utilities and commands. Overlay scaling, and rotating amounts can now be specified by numeric entry versus fixed increments as in the past. This implies that matching the overlay to the SAR can be performed more quickly. A cursor was added at the centre of the overlay to represent the ship's position. Once the overlay has been referenced to the SAR imagery, the cursor indicates the ship's position.

The use of the overlay method permitted the discovery that the requirements for the enhancement algorithms were drastically less than previously expected. It was found that through experimentation, only a few features extracted from the radar image could be used to correlate to the SAR imagery, as long as those features were significant. Also of interest is the fact that different algorithms will extract different features from the radar imagery, that in most cases can be correlated to the SAR imagery. Different algorithms can be used for different conditions. For example, one algorithm could be most effective at extracting edges, while another could be most effective at extracting ice floes. Both features could be overlaid separately, or combined in one single overlay for simultaneous correlation. In short, most features found in the radar image (using whichever algorithm), will correspond, with a high probability, to an identifiable feature on the SAR imagery.

The phase II of the project is now considered over, as a method has been developed that is directly implementable on board the ship. Recommendations will be made in the final report for continued developments in this area.

Recommendations

A) One immediate requirement is the collection of adequate radar imagery for continued developments and analysis. Significant improvements can be gained from the utilisation of better quality radar images from the new Arctic Marine Radar System recently installed on board the M.V. Arctic. It is suspected that the useful range of the radar image is much higher than first suspected and that enhancement techniques will extract information that is not visible on the usual radar PPI display.

B) Investigations should be made to find a suitable recorder to perform the task of collecting radar images. This data collection effort should be scheduled for the last fall 1989 trip of the M.V. Arctic, during which the most significant combination of ice types and correlated SAR imagery are available.

C) A last meeting should be held to determine the orientation of Phase III of the project.

Radar Image Enhancement Project
Visit Report (3rd visit)

Scope

The third and last meeting to occur was held at Canarctic's offices in Ottawa on October 16, 1989. The purpose of the meeting was to determine the orientation of Phase III of the project. We discussed the several possible orientations, the feasibility of each, and the schedule and hardware constraints.

Discussion

The status of the Radar Image Processing and Enhancement (RIPE) project is such that Phase III will require special hardware for efficient development. The time required for the execution of algorithms and methods developed during Phase I and II of the project, can be as much as 20 minutes or more, and hours for combinations of methods. Given that no other work can be efficiently undertaken by the operator while waiting for the results of a trial, the waiting time is essentially waisted time. Since the development is at a phase of refinement (which is essentially trial and error based), many trials will be needed before a suitable combination of methods and parameters can be found.

The use of dedicated hardware will have two effects:

A) Reduce the time required for the completion of a fixed amount of trials

B) Increase the number of trials that will be made. This effect comes from the fact that the user can (and will) be more liberal with the number of trials made to test a certain concept. Otherwise, the number of trials would have been kept to a minimum.

The SINSS Second Generation project (the G2 project) has a goal of defining all the functions, tasks and requirements for an integrated ice navigation system. Without expanding further on this subject, one of the end products of this project will be the core for a request for proposals aimed at defining a suitable hardware base for continued SINSS developments and the incorporation of existing Ice Navigation technologies (STAR-VUE, MARINE-VUE, etc..).

The active period of the G2 project will last for a calendar period of at most 4 months. The Phase III of the RIPE project should begin shortly after the beginning of the G2 project. The hardware recommendations from the G2 project will not be available until its completion and therefore will not be available to guide the choice of hardware for the RIPE project.

The question should then be asked; would a choice of hardware in the frame of the RIPE project conflict with the objectives of the G2 project that aim at supplying the basis for hardware choice? In appearance yes, but after analysis indications are that the conflict might be minimal. In the analysis, the following conclusions have been reached:

1) The application is specific enough that there will be a limited choice in the available hardware capable of handling the task. It is known at this point, that the choice will be limited to a few options.

2) Regardless of the hardware chosen for the G2 project, the same hardware would be chosen for the RIPE project because of the high degree of specific task requirements and the limited hardware available. In fact, the requirements are such that a choice based on other requirements would certainly be detrimental to performance.

3) By the time the hardware is to be chosen for the RIPE project, sufficient information should be available from the G2 project to guide the choice of hardware.

4) It came to mind, that like all other components to be considered in the G2 project, the RIPE hardware requirements should serve as an input to the G2 constraints and not the opposite.

5) In the determination of the hardware base for G2, the functionality of the hardware chosen for RIPE should be taken in consideration.

6) Given what is known about the available hardware market, it is anticipated that there will be no hardware conflict between the G2 and RIPE hardwares. If an incompatibility should exist, an interface between the two hardware configurations can be performed through the numerous interface components now available on the market.

7) The RIPE hardware will be computationally intensive. Communication with the G2 hardware will be limited to data input, command and data output, all three in burst mode and not very intense. The RIPE hardware can thus be considered as an independent unit much like a SATNAV unit providing input to the system.

Recommendations

A) In order to test the concept and prove its utility beyond the experimental stage, the implemented system should be tested in the appropriate ice conditions. These ice conditions exist once a year in late fall. Other periods of the year do call for the use of SINSS related technologies but at no other time is navigation so dependant on these technologies and the ice such a mixture of diverse conditions. Testing the system during this period offers the bonus of related SAR imagery which is not always available at other times of the year.

B) It is recommended that Phase III of the RIPE project proceeds with the selection of dedicated hardware and implement the developed software onto the system. The software developments should concentrate on providing the necessary elements of a system that can be tested as early as fall 1990. If the system cannot be made ready before this date, some aspects of the program would have to be postponed to the following year.

Testing the RIPE concepts would require the availability of the following features on the system:

1) The capability to receive, store, print and display airborne SAR imagery.

2) The capability to capture, store, display and process marine radar imagery.

3) The implementation of the correlation procedure as defined in Phases I and II of the RIPE project.

4) Limited user interfaces to permit the operation of the system and the demonstration of the RIPE concepts.

C) The orientation of Phase III of the RIPE project should be as follows:

1) Define the hardware requirements based on the G2 inputs and the computational requirements of the application.

2) The selection of the hardware base for the implementation of the RIPE concept. The selection should be limited to the specific processing hardware only, with a preference to use a rental host system. The goal being to relegate the choice of hardware to the G2 project as much as possible.

3) The implementation of the algorithms on the new hardware base.

4) The refinement of the implemented algorithms and the development of the necessary utilities to do so.

5) The development of basic SAR image manipulation and enhancement facilities limited to zoom, pan, and image aspect (contrast, brightness) functions. The development of more advanced SAR image enhancement methods should be postponed to other phases of the project.

6) The development of a limited user interface to drive the application.

The development of the host system to be used for the testing is to be carried out in another project yet to be defined. It is hoped that the G2 project will provide sufficient input soon enough to allow the development of the host system (complying to G2 concepts) in time for

the fall 1990 trial. .

If this should occur, close collaboration between the two developing teams will be arranged in order to achieve the desired goal.

Phase III of the RIPE project would then conclude with the shipboard trials.